NASA (GSFC) PREPRINT X-650-73-155

X-650-73-155
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SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1

MARCH 5-9, 1973

VOLUME III—DISCIPLINE SUMMARY REPORTS

Goddard Space Flight Center, Greenbelt, Maryland
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

X-650-73-155

SYMPOSIUM ON SIGNIFICANT RESULTS OBTAINED FROM EARTH RESOURCES TECHNOLOGY SATELLITE-1

Volume III
Discipline Summary Reports

Edited by
Stanley C. Freden and Enrico P. Mercanti
Laboratory for Meteorological and Earth Sciences

May 1973

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

EDITOR'S NOTE

The papers of Volume III have been derived from the Friday Working Group Sessions of the Symposium In order to achieve a uniform format, a considerable amount of editing was performed. Although contributors were afforded an opportunity to review the editing, the time allotted them for this purpose was short in order to expedite the timely publication of this document. Therefore, while care was exercised not to alter a contributor's context, this may have happened inadvertently, in which case the editors assume full responsibility.

PREFACE

The first Earth Resources Technology Satellite (ERTS-1) was launched on July 23, 1972. In the seven months since it was activated, over 34,000 scenes of the earth have been obtained, covering all major land masses and about 75 percent of the world's land area. Some areas, such as the United States, have been imaged at least twelve times. The purpose of the ERTS program is to provide an assessment of remote sensing from a satellite as a technique for inventorying and monitoring the earth's resources to provide for better management of these resources.

This Symposium provided the first open forum where the users of the ERTS data had the opportunity to present the significant accomplishments from their investigations. It also provided the first opportunity for representatives of federal, state, and local organizations to present their views on how ERTS data are being used and will be used for solving operational resource management problems.

In order to provide maximum visibility for both the scientific/technological results as well as for the applications results from ERTS, and to provide these results in a relatively concise manner to those who could not be in attendance all week, the Symposium was structured into three parts:

(1) The first three days, after an opening introductory session on Monday morning, were devoted to contributed papers in the various disciplines. A total of 184 papers was presented. These papers are contained in Volume I; they are numbered and presented in the order that they are listed in the Abstracts. Several papers not listed in the Abstracts are contained at the end of this Volume. A summary paper pertaining to the status of the ERTS system, which was given as the first paper because of its general interest to all participants, is contained as the first paper in this Volume.

(2) The Thursday Summary Session of the Symposium was designed to summarize the significant results presented during the first three days and also to present some typical examples of how ERTS results are being applied to solving operational resource management problems primarily at the federal and state levels. Highlighting this Summary Session were addresses by Dr. James C. Fletcher (Administrator, National Aeronautics and Space Administration), the Hon. James Symington (Representative, U. S. Congress, State of Missouri), and the Hon. Ed Reinecke (Lieutenant Governor, State of California). These were followed by a summary paper on the ERTS-1 status and then by four key papers selected from the presentations made during the first three days. On Thursday afternoon, four papers were presented which summarized the significant results from the first three days in selected disciplines. Five papers exemplifying the applications of ERTS results to meeting selected

federal and state program objectives and some resource management objectives in several disciplines were then presented. The proceedings of the Thursday Summary Session are contained in Volume II.

(3) Volume III contains the reports of the Working Groups which were convened on Friday to summarize and critique the ERTS results in the various disciplines. These working groups were chaired by the respective discipline session chairmen and were composed of selected specialists in the disciplines. Opinions and recommendations expressed in these reports are those of the panel members and do not necessarily reflect an official position of NASA.

Stanley C. Freden
Symposium Chairman

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AGRICULTURE, FORESTRY, RANGE RESOURCES

William Crea
NASA, Johnson Space Center
Houston, Texas

The Agriculture, Forestry, Range Resources Working Group met on the last day of the ERTS-1 Symposium (March 5-9, 1973). The members of this Working Group (listed in Appendix 1) reviewed results presented in the 25 papers of the Agriculture, Forestry, Range Resources Sessions, as well as related results. The group also sought to identify problem areas, to suggest possible solutions, and to evaluate the status of the agriculture, forestry, range program as a whole.

The results of the agriculture, forestry, range resources papers were summarized by Charles Poulton. (This paper appears in Volume II. In addition, the paper by Baumgardner, Kristof, and Henderson was selected for presentation during the Summary Session and also appears in Volume II)

The summary presented here has four major parts:

- Crop Classification and Mensuration
- Timber and Range Resources Survey and Classification
- Soil Survey and Mapping
- Subdiscipline Areas Not Addressed

CROP CLASSIFICATION AND MENSURATION

Summary of Significant Results

Science

Results approached or exceeded the 90 percent accuracy level for crop identification of the major growing crops in an area (corn and soybeans in South Dakota, Illinois, and Michigan; field corn and popcorn in Nebraska; winter wheat in Kansas, rice, safflower, asparagus, corn, and cotton in the San Joaquin Valley of California) (Horton and Heilman; Bauer; Safir, Myers, Malila, and Morgenstern, Bizzell, Wade, Prior, and Spiers, Williams, Morrain, Barker, and Coiner; Thomson). Detection of field condition (growing crops, wet planted fields, plowed fields, harvested fields, and so on) could be done on fields as small as 4 hectares (10 acres) in the Imperial Valley on enlarged (1.62,500) color composites (Johnson and Coleman). In the San Joaquin Valley, generally reliable "signatures" for fields down to 8 hectares (20 acres) were observed on color composites (Draeger).

Field mensuration of winter wheat in Kansas was done to a high degree of accuracy (99 percent) using only a September frame of MSS Band 5 when fields of 30 hectares (80 acres) or larger were considered (Williams, Morrain, Barker, and Coiner). Using pattern-recognition techniques, accurate acreage estimates of crops in fields less than 40 hectares (100 acres) require some estimate of the amount of crop misclassified in the boundary elements (Thomson). Without such estimates, acreage determined by computer classification techniques will be biased low. The amount of bias increases with decreasing field size and is also dependent on field shape.

Crops most accurately recognized are those which are green and which substantially or completely cover the underlying soil. Mature or harvested crops usually are discriminated with lesser degrees of accuracy. Those with incomplete cover (melons) can be recognized inside their field boundaries, but false detection results outside agricultural areas due to the vegetation/bare soil component (Thomson).

With the exception of work in the Imperial Valley, the use of the temporal data in either conventional or computerized techniques did not improve the accuracy of the analyses (Johnson and Coleman; Baumgardner, Kristof, and Henderson). However, this was expected since past experience has indicated the greatest contribution of temporal data should be realized during the active growing period, prior to maturity and senescence.

No consensus in investigators' results was apparent as to which MSS band or combination of bands was the most useful. MSS Band 4 used alone appeared to provide the least information. In the winter wheat identification in Kansas, MSS Band 5 provided the best information (Williams, Morrain, Barker, and Coiner). In South Dakota, where corn and soybeans were the target, MSS Band 6 was the best single choice (Horton and Heilman). Even in composite imagery, some preferred Bands 4, 5, and 7; others preferred 4, 5, and 6; and still others indicated 5, 6, and 7 gave the best results.

Technology

A unique technique is being tested in the Imperial Valley; it combines the conventional photointerpretation of ERTS-1 color composites to determine field condition (growing crops, wet planted fields, plowed fields, bare fields, harvested fields) on each or every other ERTS-1 overpass with the input of detailed crop-calendar data for each crop into a computer. The computer program will examine the cyclic record of the field condition as an input from the photointerpretation of each of more than 8000 fields and establish the most likely specific identification based on the crop-calendar information. Although this technique was not actually at the "proven results stage" at the time of the ERTS-1 Symposium, it deserves mention primarily because it combines the best of manual survey (condition classified field by field) and computer techniques to store information and make decisions on stored and updated data. Due to the extremely large number of different types of crops grown in the Imperial Valley and the intensive farming practices used to obtain the highest yield out of the irrigated land, such a "hybrid system" may be either an interim or desired system, especially in other winter vegetable and irrigated cash crop areas. The detection of eight fields out of 8000 which did not fit the crop calendar input resulted in the discovery of a newly introduced crop. Such a result indicates that the "hybrid system" has a good probability of success, whether it be for monitoring all crops in an area, or specific crops for disease control (such as plowdown of cotton residue), or for efficient use of irrigation resources (Johnson and Coleman).

Change detection was demonstrated, using two MSS Band 7 images combined with different colored filters (Johnson and Coleman).

Temporal analysis by computerized techniques was demonstrated by taking three dates of four bands each and allowing the computer to select the best bands of each of the dates to give the best results. Due to the lateness in the season, the technique was proven but did not result in greater accuracy; full potential should be capable of being proven during the 1973 crop year (Bauer; Baumgardner, Kristof, and Henderson).

San Joaquin County was stratified into 13 agricultural strata in 30 minutes using an ERTS-1 color composite. The 13 strata differed in field sizes, relative proportion of crop types, and degree of irrigation; and thus were representative of different cropping practices. Resulting strata agreed very closely with soil boundaries in many cases and were much more detailed and up-to-date than those currently being used by the Statistical Reporting Service (SRS) for its inventory work. (Whether this would result in better SRS estimates remains to be proven (Draeger).)

In the San Joaquin County study, after the point-by-point classification was made, each point was reclassified by the computer with an algorithm that considers the classification assigned to neighboring points. This algorithm improved the point-by-point classification from 10 to 30 percent depending on the homogeneity of the field (Draeger).

In Kansas winter wheat identification, wheat was associated with light and medium tones on MSS Band 5 on sandy and nearly level clay soils; whereas on nearly level to rolling loamy soils, only light tones were associated with winter wheat; thus landform and soils information was a vital part of this technique (Williams, Morrain, Barker, and Coiner).

Applications

The simplicity of the Kansas winter wheat inventory, plus the necessity for knowledge of the local crop cycles, landforms, and local environment information, make this method suitable at the county level. Statistically selected counties might perform an analysis such as this on a specific crop as an input to SRS acreage information (Williams, Morrain, Barker, and Coiner).

The hybrid inventory system described in the preceding subsection (Technology) has been applied to 8000 fields and 1860 square kilometers (460,000 acres). For this analysis, the system required 5 to 6 hours of field condition interpretation, 25 to 30 hours of keypunching, and 30 seconds of computer time (Johnson and Coleman).

Plowdown monitoring of cotton for bollworm control has already received the attention of the California State Department of Agriculture.(Coleman, Johnson, and Lewis). Maps showing locations of all cotton fields will be distributed to agricultural commissioners to test reliability and accuracy of identifying the cotton fields. The present method requires 4 man-days each month for 3 months. Use of ERTS-1 data would reduce that to two hours per ERTS-1 cycle, plus updates.

Work in Illinois on three counties showed that equally good performance was obtained regardless of which county fields of corn and soybeans were used as training sets to classify crops in the other two (Bauer). The implication is that "signature extension" is possible using ERTS-1 data, so that random selection of sample units would be possible for inventorying the acreage of several crops in a region with very small sampling error.

Stratification of San Joaquin County into 13 agricultural strata in only 30 minutes should be of use to SRS (Draeger).

Summary of Problem Areas

Science

Due to the late launch of ERTS-1, almost all crops were in the last stages of the growing cycle (corn, soybeans, rice) or harvested (barley, wheat). Therefore, although results of crop identification accomplished on 1972 crops were encouraging, the earliest point in the growing cycle at which each crop can be accurately identified and measured—and not be confused with other crops—is not yet known. The earlier in the season, the more the information is worth to SRS, ASCS, agri-businessmen, and others (Johnson and Coleman; Bauer; Baumgardner, Kristof, and Henderson; Bizzell, Wade, Prior, and Spiers, Williams, Morrain, Barker, and Coiner; Horton and Heilman).

We will have no measure until the 1973 crop year of whether temporal data improve identification accuracy (Bauer; Baumgardner, Kristof, and Henderson).

Technology

Although almost every investigator in the area of vegetation identification uses some form of crop calendar, each investigator has to develop his own for his particular investigation. Since the crop calendar is an integral part of crop (or vegetation) identification, a regional, national, or international crop inventory can not be undertaken until crop calendars are available at least regionally. The crop calendar not only aides photointerpreters, but also is essential for design of an operational computerized system so that one will know when certain farming practices are undertaken that would be indicative of a specific crop. Regional crop calendars may allow programs to be written with built-in weighting factors based on a priori knowledge of the region combined with maximum likelihood classifiers or clustering techniques (Johnson and Coleman; Baumgardner, Kristof, and Henderson; Bauer; Bizzell, Wade, Prior, and Spiers; Williams, Morrain, Barker, and Coiner; Horton and Heilman).

Refinement is required in computer and software techniques to allow greater numbers of crops to be classified at the same level of accuracy. There is a great temptation to classify only that which yields good results and to threshold everything else, or to classify what is important and to disregard the less important as unnecessary additional work.

Applications

Only a limited number of conventional interpretation investigations provided figures from which cost/benefit ratios could be derived. None of the pattern recognition investigations provides any figures on the computer time required to do an acceptable classification or on cost per computer hour.

Investigators doing only crop identification work should be strongly encouraged to include acreage estimates as part of their work for obvious value in applications areas.

Only a limited number of investigators are concerning themselves with developing and perfecting sampling models, and those to date have been within an ERTS frame. More work should be done on sampling models and signature extension between frames (Bauer; Baumgardner, Kristof, and Henderson; Johnson and Coleman).

Only a limited number of investigators are working with eventual users (SRS, ASCS, agribusiness) and most of these are at the local level (Bauer; Baumgardner, Kristof, and Henderson; Bizzell, Wade, Prior, and Spiers; Draeger).

Assessment

From the standpoint of applications, almost every investigation lacked complete definitions of techniques and procedures which would allow a quasi-operational crop inventory project to be undertaken. More involvement with the eventual users—whether the user is USDA or agri-business—would solve many of the technical problems, such as type of output required, development of a regional or national crop calendar and data bands applicable to remote sensing data. Involvement with the user on at least a regional basis would also allow "objective" evaluation by the eventual user of how best to make use of the information. It appears that crop identification and acreage measurement is at a stage where NASA in conjunction with several agencies within USDA and agri-business should select several investigators to pursue refinement of techniques and procedures (including sampling methods, regional and national crop calendar generation, signature extension, and so forth) in preparation for conducting a large-scale demonstration project over an area of several states and involving one or more of the major crops (wheat, corn, cotton). User agencies should share in the responsibility, conduct, and cost of the project, with project objectives to include accuracy determinations and cost effectiveness studies, and the ultimate goal to be technology transfer

TIMBER AND RANGE RESOURCES SURVEY AND CLASSIFICATION

Summary of Significant Results

Science

In the "Brown Wave" experiment, softwood, mixedwood, hardwood, agricultural land, and water were successfully mapped using MSS Bands 5 and 7 and a dot grid to measure areas. Classification into the five named categories required less than 30 minutes for 2.2 square kilometers (5500 acres) (Dethier, Ashley, Blair, and Kopp).

Use of Brown Wave data and techniques shows the feasibility of development and refinement of phenoclimatic models for study of wildlife habitat conditions and availability (Dethier, Ashley, Blair, and Kopp).

Photointerpretation of a color composite of MSS Bands 4, 5, and 7 of the Seward Peninsula, Alaska, required only 10 man-hours to delineate seven vegetation types of which only four are described on existing vegetation maps. In addition, significantly more detail in distribution of these vegetation types is available from ERTS-1 data than is available on existing maps. Various ages of old to new vegetation, burn scars, and rate of revegetation of these scars were also identified. Use of such a vegetation map is of particular importance to remote areas for watershed management, wildlife management, and land-use planning (to delineate areas to be managed for caribou, moose, and waterfowl as well as areas which might be opened to homesteading or managed for trapping of fur-bearers) (Anderson, Shapiro, and Belon).

Use of MSS Band 5 imagery and MSS Bands 4, 5, and 7 color composites of August 1972 of the Nebraska Sand Hills indicated that range sites could be recognized and forage density differences could be qualitatively distinguished on the sandy sites. In addition, the color composites allow contrast to be detected in the subirrigated areas. Soil vegetation relationships appear the same on the color composites as on high-altitude color-IR photography (Seevers and Drew). Using MSS Band 7, the Sand Hills investigation detected and delineated the boundaries of a large recent grass fire and resulting soil erosion after loss of vegetative cover, to a greater degree of accuracy than previously available. The study also suggests that ERTS-1 data could be used to select sights amenable to irrigation by center-pivot systems.

A range study in California concluded that gross mapping of rangeland was possible; however, not enough detail (resolution) was available for district managers and ranchers to determine carrying capacity of native grassland (an exception might be improved grassland/pastures, because such areas are more homogeneous) (Carneggie).

The most significant contribution of ERTS-1 to California rangelands is monitoring changes in plant condition and development (coupling of sequential negative and positive transparencies highlighted the change). Detection and monitoring of progressive draw-down and depletion of surface-water reservoirs and drying of forage were demonstrated, as well as the "Green Wave" effect of annual grasses after a rainstorm (Carneggie).

Conditions of California rangelands (relative greenness or dryness) can be monitored to provide information on fire hazard potential, anticipated rate of gain of livestock or rangelands and when rangelands should be closed to grazing because of dryness and scarcity of forage (Carneggie).

Using MSS Band 7, an accurate identification and delineation of crested wheat-grass seedlings has been accomplished for the first time for the entire state of Nevada. The work required 2 man-weeks of labor and provides a broad but detailed inventory of those areas where native grasses have been plowed and planted to wheat grass to increase grazing potential. Also, recognition of variations in reflectance in the seedlings was noted, which may be due to grazing intensity, precipitation, and so forth (Tueller and Lorain).

Pinon/juniper communities in Nevada with a density of 75 trees per hectare (30 per acre) and larger than 22- to 24-hectare (55- to 60-acre) blocks can be identified on ERTS-1 color composites (much of this type of rangeland is used for grazing and is extremely important for deer and elk winter range in many western states) (Tueller and Lorain).

Based on secondary-sucession textural changes, burn scars in Nevada are easily identified, measured, and classified by age into less than 1 year, 1 to 10 years and older than 10 years (Tueller and Lorain).

By using MSS Band 7, water standing in the numerous playas in Nevada can be detected and sequentially monitored. Bands 4 and 5 give an indication of the quality of the water. The presence of water standing in playas indicates recent rainfall in the local watershed (Tueller and Morain).

In the Houston area, delineations were achieved between marsh wetlands, water, upland prairie, and woodlands–both by computerized and conventional techniques (Heath and Parker).

In the Davis Lake study area of California, a quantitative image interpretation test of ERTS-1 imagery showed that broad resource type identification (coniferous forest, hardwood forest, mountain chaparral, xeric grassland, mesic rangeland, sagebrush scrub, cultivated crops, and exposed soil) could be identified to an accuracy level of 70 percent. This accuracy is expected to improve significantly with the availability of sequential data during the 1973 growing season (Lauer and Krumpe).

In the Bucks Lake study area of California, ERTS-1 imagery yielded less detailed information than conventional aerial photographs, but the type delineations were drawn 20 times faster than when using 1:15,840 scale black-and-white photos and nine times faster than when using 1:120,000 scale color-IR photos. The less important boundaries were the ones most often misplaced or omitted. Using ERTS-1 imagery, stratification and classification of 20,000 hectares (50,000 acres) of vegetation and terrain resources in the Bucks Lake area required 2¼ hours (Lauer and Krumpe).

A quantitative image interpretation test in the San Pablo Reservoir area showed that differentiation between various types of woody vegetation was difficult—Monterey pine was identified correctly 78 percent of the time, with mixed hardwoods, eucalyptus, and chaparral scoring less than 50 percent accuracy However, in the same test it was shown that woody vegetation could be discriminated from other types 86 percent of the time (Lauer and Krumpe).

Using ERTS-1 imagery, the perimeter of a large forest-fire burned area and damage levels within the burned area were mapped significantly more accurately compared to the estimate made by the California Division of Forestry. Accuracy was verified by low-altitude photography The cost of mapping the burned area using ERTS-1 data was one-tenth that of doing it by conventional methods (Lauer and Krumpe).

In the Houston area, computerized processing using clustering techniques yielded a 70 percent agreement between ground truth and areas classified into pine stands, hardwood stands, and pine regeneration stands. Conventional image interpretation techniques yielded less accurate results (63 percent) and took considerably more time—as reported in other papers—for similar accuracy. Data from the 1973 season should improve the accuracies obtained using either computer or conventional techniques (Heath and Parker).

Technology

A step-wise discriminant analysis (SWDA) was described for work in the Arizona area. This technique relates plant species to terrain features (elevation, macrorelief class, aspect and slope, drainage class, and soil type). Such a technique, when combined with multistage aircraft sampling, appears to be very promising in the arid-land vegetation areas (Schrumpf).

Applications

Successful mapping of wildland vegetative resources even to a relatively broad scale allows some judgment to be made regarding how the area should be managed for a watershed management, wildlife habitat use, livestock grazing use, and recreation and development impacts. This broad-based information becomes even more valuable in remote and sparsely populated areas such as Alaska and Nevada (Anderson, Shapiro, and Belon; Tueller and Lorain).

Monitoring rangeland changes within a growing season and between growing seasons for both perennial and annual grasslands strongly suggests that regional prediction models could be developed to forecast the rate of gain of livestock on rangeland based on relative greenness or dryness, whether the present year is better or worse than past years, fire hazard potential due to dryness, and so forth (Carneggie).

In almost all the forestry and range resource investigations, various user agencies had been contacted and were involved to varying degrees in using the data or evaluating the usefulness and submitting their particular user requirements.

Summary of Problem Areas

Science

The lateness of the ERTS-1 launch appeared to seriously affect the accuracy of identification of wildland vegetative resources and to restrict the classification to relatively broad categories. Most investigators are anticipating better results using 1973 growing season data—in particular the spring sequential development of plant communities—to perform classification of more specific categories.

The nonhomogeneous nature of most wildland vegetation (softwoods, hardwoods, shrubs, grasses, and so on) growing in irregular patterns has presented more complex problems than agricultural crops—not only in classification by conventional methods but in implementing pattern-recognition techniques.

Technology

Due to the nonhomogeneous nature of most wildland vegetation as compared to agricultural land, classification accuracies of usable classifications, whether using conventional or computer techniques, have not approached the results achieved in agriculture. To improve these accuracies with present sensors, timing of data acquisition is more critical (for spring development), and multistage sampling using aircraft data to bridge the gap is indicated.

Applications

Although many users are involved to varying degrees with several of the investigators, user data requirements are dictated by their region or state; therefore, there is very little uniformity between investigators' results (format and categories of vegetation classification). It was strongly suggested by one of the members of the Working Group that vegetation mapping on a regional or state scale (presently being done by several investigators) should be a coordinated effort, with development of a *common classification scheme* (such as an ecological vegetation legend or adoption of the land-use classification scheme in USGS circular no. 671). However, the majority of the panelists felt an ecological-vegetation-legend system would be more workable than one which had a land-use bias.

Assessment

ERTS-1 is well suited for broad to relatively specific vegetation classification and distribution and for monitoring changes in distribution and condition. In these tasks, the information from ERTS-1 data can be used for policy making (possibly to identify areas where plowing and reseeding to introduced grass species would be advantageous) and for land-use planning and management. Current developments indicate that ERTS-1 may not be capable of providing the detailed information needed for intensive management of rangelands.

The demonstration of accurately identifying vegetation and distribution was only marginally shown by work done in the fall of 1972. The data collected on the differential greenup and rate of growth between species and plant communities should allow considerably more accuracy to be obtained using 1973 data.

There is a definite need for standardizing the categories of wildland vegetation classification. It was felt the categories suggested in USGS circular no. 671 were not sufficient to accomplish the required task. An ecological vegetation legend was suggested. However, considerable effort will be needed to coordinate the generation of such a common classification scheme applicable on a national or international scale.

It was felt the identification of wildland vegetation features was not at the same level of development as the work in agriculture, primarily because of the nonhomogeneous, complex, and irregular distribution of plant species and communities. It was strongly felt that some degree of multistage sampling will be required to solve many of the range and forestry inventory problems to an acceptable degree of accuracy and mensuration (Poulton and Welch; Schrumpf; Tueller and Lorain; Seevers and Drew; Carneggie; Lauer and Krumpe; Heath and Parker).

Involvement with the user agencies was good; however, in most cases it is at a local level. There is a need to have more than local involvement if any technology transfer is to occur which could be implemented agency-wide.

Only a limited amount of computer analysis is being done. Considerably more work needs to be done in this area to handle the volume of data for both range and forestry which would be available for use in an operational system.

As was the case in agriculture, the true worth of ERTS-1 data will not be known until analyses of data from the 1973 growing season are accomplished to allow full advantage to be taken of sequential data or data acquired at specific times during the growing season to allow differentiation of range and forest species of communities.

SOIL SURVEY AND MAPPING

Summary of Significant Results

Science

Three soil associations in Tennessee were delineated through the reflective characteristics of a fairly uniform cover of vegetation using computer analysis of output from a scanning microdensitometer of MSS Band 7 imagery (Parks).

In Colombia, approximately eight soil associations were derived from 1:500,000 scale enlargements of MSS Bands 5 and 7 imagery. Most of the important units of an existing 1:250,000 scale aerial reconnaissance soil map could be extrapolated successfully into an unknown similar area using ERTS imagery in conjunction with sample strips of 1:60,000 aerial photography. The interpretation of the unknown area on ERTS was verified later by interpretation of aerial-photo sample strips. In those areas where delineations were unsatisfactory, it is anticipated that repeated ERTS coverage will improve results (Elbersen).

Work in South Dakota (detailed results are presented in the Land-Use summary but are discussed here) used each of the four MSS bands viewed singly and a color composite of MSS Bands 4, 5, and 7 with three-power magnification. The color composites proved to be the most useful, with MSS Bands 5 and 7 being the next most useful imagery. There was general agreement between existing soil maps and those derived from ERTS-1 color composites; however, the delineations from ERTS-1 data improved the accuracy of many of the soil associations recognized in South Dakota. Steep valley sides, broad interfluves, and contrasting textures are all clearly visible on the ERTS-1 color composites. The 3-million-hectare (8-million-acre) scene that can be scanned in one frame allows comparisons of soil associations over their entire extent, all at the same instant in time and growth and with all features in proportion. This makes anomalies readily apparent and allows vegetative differences (which are usually a function of different abilities of the different soil associations to produce vegetation) to be used effectively to help separate soil associations (Westin and Myers).

Technology

MSS Bands 5 and 7 and color composites were the most useful in delineating soil associations (Elbersen; Parks; Westin and Myers).

Applications

The soil-association map produced in Colombia will be very useful in the first stages of planning in remote, undeveloped areas and this technique can yield significant practical results in developing countries (Elbersen).

The general technique used in the South Dakota investigation should be applicable in other areas having well-defined landscape features (Westin and Myers).

Capturing a 3-million-hectare (8-million-acre) area at one instant in time with vegetative cover should allow refinement of existing soil-association maps of many areas, since an entire association is displayed (anomalies not previously apparent become apparent at this scale with true contrasting tones and proportionality). Sequential ERTS-1 data and seasonal data should yield additional information (Westin and Myers).

Summary of Problem Areas

Science

Additional work or results in areas of different terrain and vegetation is needed to determine if the success reported in the three papers discussed is generally applicable to mapping soil associations nationwide or where problems occur.

Technology

No technical problems were apparent in the papers presented. We may want to determine whether conventional interpretation or computerized processing would be the most cost effective.

Applications

Soil-association maps are very valuable for land-use planning and are a necessary first step toward more detailed soil surveys which require soil profiles and contact sensing. No interpretation times or costs were given to derive cost/benefit ratios. However, these ratios should be easily obtainable and should be highly favorable (Elbersen; Parks; Westin and Myers).

Assessment

Soil-association mapping appears to present little problem in the three papers discussed. Verification is needed of favorable results presented with work in other areas, especially sections of country which do not have existing soil-association maps or have complex soils or soil problems (saline or alkaline soils). We need to determine cost/benefit figures and whether computerized analysis would add significantly without increasing cost.

SUBDISCIPLINE AREAS NOT ADDRESSED

Summary

The subdiscipline areas of soil moisture and water utilization-evapotranspiration were not reported in the Agriculture Forestry Range Resources Session. Only qualitative statements of soil moisture (wet or dry) were addressed in crop-identification papers as parameters of field condition. Soil-moisture and water-utilization studies may have been addressed in more detail in the Water Resources Session. Significant results in detection of plant stress per se were not reported during the ERTS-1 Symposium. Papers were presented in which dead trees had been detected using primarily aircraft data, and in one case relating the dead tree areas known by ground truth or aircraft data to ERTS-1 data and separating areas of dead trees in large, medium, and small areas using enlarged color composite imagery.

Summary of Problem Areas

Quantitative measurement of soil moisture appears to require sensors not on ERTS-1 (such as thermal infrared or microwave sensors).

Detection of stress (nutrient deficiency, drought, insect infestation or disease, hail, saline areas, and so forth) requires sensing reflectance from vegetation that is not in a mature, senescent, dormant, or harvested state. The late launch of ERTS-1 prevented acquisition of such data within the U. S. In addition, the primary emphasis of most investigators has been in the identification and mensuration of vegetative features; detection of stress was secondary unless it was a parameter interfering with the primary objectives.

Assessment

Most soil-moisture studies would be reported in the Water Resources Session. Quantitative results on soil moisture will probably not be available until data are available from thermal or microwave sensors.

Progress in detecting plant stress should be made during the 1973 growing season using ERTS-1 data. A quantum jump in detection of plant stress is anticipated when thermal data become available.

APPENDIX 1

PARTICIPANTS IN THE ERTS-1 AGRICULTURE, FORESTRY, RANGE RESOURCES WORKING GROUP

Marion Baumgardner
LARS/Purdue University
West Lafayette, Indiana 47906

William Crea, Chairman
NASA/Johnson Space Center
Houston, Texas 77058

Harold Mathews, Cochairman
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Charles Olson
University of Michigan
Ann Arbor, Michigan 48105

Denny Parker
LEC/Johnson Space Center
Houston, Texas 77058

Charles Poulton
Oregon State University
Corvallis, Oregon 97331

Barry Schrumpf
Oregon State University
Corvallis, Oregon 97331

Craig Wiegand
USDA/Agricultural Research Service
Weslaco, Texas 78596

APPENDIX 2

PAPERS PRESENTED IN THE AGRICULTURE, FORESTRY, RANGE RESOURCES SESSION

AUTHOR(S)	TITLE
Anderson, James H., Lewis Shapiro, and Albert E. Belon (A8)	Vegetative and Geologic Mapping of the Western Seward Peninsula, Alaska, Based on ERTS-1 Imagery
Bauer, Marvin E. (A25)	Identification of Agricultural Crops by Computer Processing of ERTS MSS Data
Baumgardner, M. F., S. J. Kristof, and J. A. Henderson (A26)	Identification and Mapping of Soils, Vegetation, and Water Resources of Lynn County, Texas, by Computer Analysis of ERTS MSS Data
Bizzell, Robert M., Lewis C. Wade, Harold L. Prior, and Bobby Spiers (A23)	The Results of an Agricultural Analysis of the ERTS-1 MSS Data at the Johnson Space Center
Carneggie, David M. (A11)	Monitoring California's Forage Resource Using ERTS-1 and Supporting Aircraft Data
Coleman, Virginia B., Claude W. Johnson, and Lowell N. Lewis (A15)	Evaluation of Remote Sensing in Control of Pink Cotton Bollworm
Colwell, Robert N. (A18)	ERTS-1 Imagery and High Flight Photographs as Aids to Fire Hazard Appraisal at the NASA San Pablo Reservoir Test Site
Dethier, Bernard E., Marshall P. Ashley, Bryon Blair, and Richard J. Kopp (A19)	Phenology Satellite Experiment

Draeger, William C. (A24)	Agricultural Applications of ERTS-1 Data
Elbersen, G. W. W. (A13)	Interpretation of ERTS MSS Images of a Savanna Area in Eastern Colombia
Hall, Ralph C. (A16)	Detection and Monitoring of Forest Insect Infestation in the Sierra Nevada Mountains of California
Heath, G. R. and H. D. Parker (A20)	Vegetation Mapping in the Houston Area with ERTS-1 Data
Heydt, H. L. and A. J. McNair (A5)	Engineering Analysis of ERTS Data for Southeast Asian Agriculture
Horton, Maurice L. and James L. Heilman (A3)	Crop Identification Using ERTS Imagery
Johnson, Claude W. and Virginia B. Coleman (A2)	Semi-Automatic Crop Inventory from Sequential ERTS-1 Imagery
Lauer, Donald T. and Paul F. Krumpe (A12)	Testing the Usefulness of ERTS-1 Imagery for Inventorying Wildland Resources in Northern California
Lopez de Sagredo, Fernando and Francisco G. Salinas (A4)	Identification of Large Masses of Citrus Fruit and Rice Fields in Eastern Spain
Parks, W. L. (A14)	Delineations of Major Soil Associations Using ERTS-1 Imagery
Poulton, Charles E. and Robin I. Welch (A6)	An Interregional Analysis of Natural Vegetation Analogues Using ERTS-1 Imagery
Safir, Gene R., Wayne L. Myers, William A. Malila, and James P. Morgenstern (A21)	Application of ERTS-1 Data to Analysis of Agricultural Crops and Forests in Michigan
Schrumpf, Barry J. (A7)	Natural Vegetation Inventory

Seevers, Paul M. and James V. Drew (A10)	Evaluation of ERTS-1 Imagery in Mapping and Managing Soil and Range Resources in the Sand Hills Region of Nebraska
Thomson, F. J. (A22)	Crop Species Recognition and Mensuration in the Sacramento Valley
Tueller, Paul T. and Garwin Lorain (A9)	ERTS-1 Evaluations of Natural Resources Management Applications in the Great Basin
Williams, Donald L., Stanley A. Morrain, Bonnie Barker, and Jerry C. Coiner (A1)	Identification of Irrigated Winter Wheat from ERTS-1 Imagery

Supplemental Program

Westin, Frederick C. and V. I. Myers (L11)	Identification of Soil Association in South Dakota on ERTS-1 Imagery

LAND USE AND MAPPING

D. Wayne Mooneyhan
NASA Earth Resources Laboratory
Bay St. Louis, Mississippi

INTRODUCTION

During the ERTS Symposium, 28 papers were presented during the Land Use and Mapping Sessions. On March 9, 1973, the last day of the Symposium, a Working Group met to evaluate the Land Use and Mapping presentations. The members of this Working Group are listed in Appendix 1; the Land Use and Mapping presentations (which are in Volume I) are listed by author and title in Appendix 2.

This report is presented in three parts: Mapping Investigations, Land-Use Inventory–Image-Interpretation Techniques, and Land-Use Investigations – Automatic Pattern-Recognition Techniques. Within each of these sections, results and problem areas are summarized and the Working Group's assessment of the program status is presented.

MAPPING INVESTIGATIONS

Summary of Significant Results

Science

The capability of Band 7 (0.8 to 1.1 micrometers) to penetrate some thin clouds and contrails is far better than was expected (Colvocoresses). This indicates that the use of this band is of high potential value in areas where atmospheric conditions may be marginal in the visible bands.

Technology

From the mapping viewpoint, ERTS has exceeded expectations. Image quality (MSS-bulk) permits meaningful products to be produced at up to at least 1:250,000 scale. Geometry now limits mapping at National Map Accuracy Standard (NMAS) of ERTS MSS to a scale of 1:1,000,000 or perhaps 1:500,000. However, there is evidence that by applying corrections based on ground control that geometric accuracy can be improved without sacrificing image quality.

ERTS has demonstrated several advantages of the electronic transmission mode of earth sensing as compared to existing or proposed film return systems (aircraft or spacecraft) as follows:

- Long life and coverage
- Near real time
- Orthogonality
- Radiometric fidelity
- Extension into the near infrared

Applications

The investigations have shown that the ERTS imagery can be used for cartographic photo-base products at scales of 1:500,000 and smaller. In addition, the ERTS imagery can be used for photographic products to complement existing line maps at scales at least as large as 1:250,000. ERTS imagery can be used to support the revision of existing line maps at a large variety of scales.

Summary of Problem Areas

Science

A need exists to better understand the response in wavelengths previously unavailable to cartographers.

Technology

The geometric fidelity must be increased, but—at the same time—the original image quality must be maintained. Also, an increase in the knowledge of the absolute position of the spacecraft and the attitude of the sensors to permit mapping independently of ground control is needed for mapping in remote areas.

A problem exists in identifying the ground control points, and a need exists for higher ground resolution in one spectral band (Colvocoresses). This could probably be best achieved using an imager such as the RBV equipped with longer focal-length optics. Quantitative ground resolution figures are unavailable because of the lack of a suitable calibrated ground resolution target.

Applications

Optimum processing necessary to convert ERTS imagery into finished cartographic products suitable for distribution to the public is required.

Assessment

ERTS has demonstrated an effective cartographic system that should evolve into an operational capability. Investigations covering the various aspects of mapping should be continued in order to better define the limitations and capabilities of the ERTS system. Efforts to increase geometric fidelity of the MSS imagery while preserving image quality should be accelerated. It is believed that in any operational system all remotely sensed observations must be referenced to the figure of the earth with some defined degree of precision. To achieve this goal, solution of the mapping problems indicated are essential.

LAND-USE INVENTORY—IMAGE INTERPRETATION TECHNIQUES

Summary of Significant Results

Science

All four of the MSS bands are useful to the interpreter, however, Band 5 (0.6 to 0.7 micrometers) and Band 7 (0.8 to 1.1 micrometers) provide most of the information and are more easily interpreted.

Geometric accuracy of ERTS images is adequate for the interpretation of land use. Objects as small as 100 m (300 ft) in diameter and linear features as narrow as 15 m (50 ft) have been identified. Repetitive coverage (that is, seasonal) increases accuracy and number of categories considerably, but the full value of this aspect is not yet known.

Technology

Conventional image-interpretation techniques aided primarily by color-additive viewers, image-density enhancement, and magnification up to 20 times, were explored.

ERTS data provide resolution capability for classification beyond the nine Level I categories indicated by the Land Use Classification Items Committee. Fourteen to 18 categories of land use have been mapped. Rural land-use categories have been inventoried to 95 percent accuracy in some areas. Rural/urban interface identification has been accomplished in several areas. Coniferous trees were separated from deciduous trees under certain seasonal and climatic conditions.

The need for detailed investigations in specific areas has been discovered by investigators reviewing ERTS data for these areas. (The detailed studies required systems with higher resolution or ground level studies in most cases.)

Applications

Land-use inventory and mapping have been carried out for the states of Rhode Island, Massachusetts, and Connecticut, and agencies of those states are being introduced to the output products and production techniques (Simpson and Lindgren).

The Joint Federal-State Land Use Planning Commission of Alaska (10 state and federal operating agencies) is making use of inventory information in that state. ERTS system products include: land-use inventory for the purpose of aiding in the selection of 880,000 square kilometers (220 million acres) of public domain land, identifying and preserving land suited for agriculture; forest location and management, including assessment of damage by fire and infestations; pipeline and highway location and associated ecological impact studies (Miller).

Land-use inventories are being conducted in several states (Wisconsin, Minnesota, Michigan, and Wyoming) at various levels of classification for use along with other types of information for land and resource management. An example is the use of inventory information in the enforcement of laws concerning wetlands management. In Minnesota, the format of the inventory is such that it can be used to update an operational statewide land management system (Brown et al.)

State and regional planning agencies in Wisconsin; Los Angeles County, California; and Oakland County, Michigan, are using land-use inventory to map and monitor urban growth into surrounding open, agricultural, and recreational areas. Urban boundaries were mapped for use in the Federal/State Revenue Sharing Program in Los Angeles County, California (Raje et al.).

Kern County, California is utilizing land-use inventory to predict water usage and thereby affect stream management (Estes).

Land-use maps were utilized in a Pennsylvania mining area to identfy water resources where water quality could be affected by runoff from refuse areas (Borden et al.).

In the Central Atlantic Regional Ecological Test Site (CARETS), land-use maps were utilized to identify critical areas for detailed study (Dolan and Linwood, Alexander).

Summary of Problem Areas

Science

Resolution is not adequate for detailed urban land-use classification. Also, in arid areas, some difficulty was experienced in identifying fallow fields

A higher number of categories is possible with complete seasonal variation. To date, investigators have data usually from only one, and at the most two, seasons. (This problem will, of course, cease to exist with continued operation.)

Technology

Present image-enhancement techniques and procedures are slow and tedious. Automated methods of image enhancement need to be developed.

Applications

Detailed, step-by-step procedures for obtaining the optimum number of land-use categories need to be developed and documented, and cost-effectiveness studies need to be conducted and documented.

Assessment

A variety of investigations involving conventional image and interpretation techniques were reported during this session of the ERTS-1 Symposium. These investigations were supplemented in some cases by state-of-the-art image enhancement and viewing equipment, applied in areas ranging in size from one county to three states, for the purpose of land-use inventory. The aims of the various investigations range from development or evaluation of techniques and evaluation of ERTS data for use with known techniques to operational applications of inventory results. Many of the investigators reporting in the conventional image-interpretation area considered that the operational feasibility of this approach has been proven for rural and regional applications. They generally agree, however, that accuracy and usefulness can be improved by further analysis of seasonal variations. In the area of image enhancement, the next step for NASA should be to identify and fund investigations directed towards the finalization of a technique and detailed procedure for converting ERTS imagery into the best possible land-use inventory. Investigations should include accuracy determination based on one-time coverage by ERTS imagery and seasonal or repetitive coverage of ERTS imagery. The investigations should further include a cost-effectiveness study based on small-scale demonstrations by the investigators. A final step should include several large-scale demonstrations (statewide) of the finalized procedure in various parts of the United States representing a cross section of terrain and topography; these large-scale demonstrations should be joint projects between NASA and the user agencies. The evaluation (made by users and NASA) of the final results of these large-scale demonstrations, including problems of technology transfer, could then be documented for use by interested states or regions.

It should be noted that for urban areas, classification by image interpretation of satellite data is inadequate for the urban planner. In order that a total information system be available for urban planning and resource management, it will probably be required that aircraft data supplement the satellite data.

LAND-USE INVENTORY—AUTOMATIC PATTERN RECOGNITION TECHNIQUES

Summary of Significant Results

Science

It was generally found that a larger number of categories could be determined by the use of all four channels of ERTS data in conjunction with automatic pattern recognition programs than could be determined from image interpretation. In urban areas, generally three to four categories could be mapped, and while an inventory to this detail is generally not useful to the urban planner, it does have some value to the regional planner in the region including the urban area.

Many of the Level II categories in areas outside urban areas could be determined, and it was generally found that Level I categories were more accurately inventoried by first accomplishing the maximum detail classification, and then aggregating Level II categories into Level I.

Technology

Land-use classifications were conducted by using a maximum-likelihood supervised classifier and a clustering unsupervised classifier, with the supervised classifier generally giving a higher number of categories and higher accuracy. This was expected, however, since much work has been done with maximum-likelihood supervised classifiers, whereas clustering is a more recent development.

Applications

The regional planning commission in Los Angeles, California, utilized products to identify urban boundary lines for revenue-sharing purposes, and also as input to regional planning base data (Raje et al.).

The refuse from strip mining in a large coal region in Pennsylvania was mapped along with the associated water resources that were affected by the runoff from these refuse banks (Borden et al.).

Output products were utilized in Los Angeles County for identification of areas that were potential fire dangers in the outlying areas, and for identification and delineation of areas that had been damaged by fire (Raje et al.).

Land use in an eighteen-county region around Houston, Texas, was inventoried to approximately Level II, and a comparison was made with existing land-use inventories and with 1:120,000 scale imagery (Erb et al.).

Wetlands, water, open lands, lands useful for future recreational needs, and lands available for transportation corridors were identified in a six-county region including Detroit and Oakland County, Michigan (Sattinger and Dillman).

The State of Michigan has been mapped to Level I categories and the information is being considered as input to the highway department's predictive model (Sellman).

Yellowstone National Park was mapped to four categories, with application planned for wildlife habitat and other resource management (Thompson).

A Summary of Problem Areas

Science

A determination and correlation of the geometric distortion of the computer product is a problem that remains to be dealt with.

Technology

More work is needed on the refinement of techniques and software to reduce the number of misclassifications both in supervised and unsupervised techniques.

Applications

The lack of quantitative evaluation of accuracies and cost effectiveness leaves too many unknowns for widespread application.

Assessment

Investigations involving both the supervised (maximum likelihood) classifier and the unsupervised (clustering) classifier, which are applied in areas ranging from small test sites to entire states for the purpose of land-use inventory, were reported during this session of the ERTS-1 Symposium. The aims of the various investigations range from developing techniques and procedures for data processing to production of land-use maps using existing procedures. The results presented in almost every investigation were lacking in total definition of techniques, refinement of procedures, accuracy determination, identity of output format, and actual evaluation and cost effectiveness by both the investigators and the users. In the area of land-use inventory using automatic techniques, the next objectives for NASA should be

- to identify from reported results an investigator or investigators to pursue the refinement of techniques and procedures for the use of the unsupervised (clustering) technique; and to concentrate and fund efforts in the development of the clustering technique at that one point or points.
- to identify adequate user requirements for information, content, and format; to finalize documentation for techniques and procedures using the supervised (maximum-likelihood) technique; and to concentrate efforts in this area at a point.
- upon the completion of the preceding objective, to select adequate large-scale demonstration projects, that is, three to four states presenting a cross section of terrain and topography and, in concert with the user organizations, conduct large-scale applications complete with cost-effectiveness studies and final accuracy determinations. The evaluation of the final results of these large-scale demonstrations, which would include the problems and opportunities of technology transfer,

could then be finalized for use by as many of the states and regions as needed and for consideration for use at the national level.

Here, again, it should be noted that classification of urban areas using ERTS-1 data cannot be done to sufficient detail to support the urban planner. However, work is presently going on in the definition and documentation of an aircraft system utilizing automatic data techniques, and this work should be considered in conjunction with the satellite as a part of the overall system for providing complete land-use inventory.

APPENDIX 1

PARTICIPANTS IN ERTS-1 LAND USE AND MAPPING WORKING GROUP

G. Robinson Barker
St. Regis Paper Company
Jacksonville, Florida 32229

A. P. Colvocoresses
USGS
McLean, Virginia 22101

William Finch
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Ernest Hardy
Cornell University
Ithaca, New York 14850

Bob Hill
NASA/Johnson Space Center
Houston, Texas 77058

A. T. Joyce, Co-Chairman
NASA/Earth Resources Laboratory
Bay St. Louis, Mississippi 39520

David T. Lindgren
Dartmouth College
Hanover, New Hampshire 03755

D. W. Mooneyhan, Chairman
NASA/Earth Resources Laboratory
Bay St. Louis, Mississippi 39520

John Place
USGS/Geographic Applications Program
Washington, D. C. 20242

Robert L. Rowley
NASA/Johnson Space Center
Houston, Texas 77058

David J. Ruml
Dartmouth College
Hanover, New Hampshire 03755

APPENDIX 2

PAPERS PRESENTED IN THE LAND USE AND MAPPING SESSIONS

AUTHOR(S)	TITLE
Alexander, Robert H. (L6)	Land Use Classification and Change Analysis Using ERTS-1 Imagery in CARETS
Alexander, Robert H (L7)	ERTS Regional-Scale Overview Linking Land Use and Environmental Processes in CARETS
Bale, Jack B., and Leonard W. Bowden (L5)	Land Use in the Northern Coachella Valley
Borden, F. Y., and Danielle N. Applegate L23)	The Use of the Temporal Dimension in Classifying and Mapping ERTS-1 MSS Data
Borden, F. Y., D. N. Thompson, and H. M. Lachowski (L24)	Identification and Mapping of Coal Refuse Banks and Other Targets in the Anthracite Region
Breckenridge, Roy, Ronald W. Mars, and Donald J. Murphy (L13)	Remote Sensing Applied to Land Use Studies in Wyoming
Brown, Dwight, Merle P. Meyer, Joseph Ullman, Steven Prestin, Dale Tripper, James Gamble, and Ralph Eller (L14)	ERTS-1 Applications to Minnesota Land Use Mapping
Clapp, J. L , R. W. Kiefer, and M. M. McCarthy (L16)	The Use of ERTS-1 Data for the Inventory of Critical Land Resources for Regional Land Use Planning

Colvocoresses, Alden P. (L2)	Progress in Cartography, EROS Program
Dolan, Robert, and Linwood Vincent (L8)	Evaluation of Land Use Mapping from ERTS in the Shore Zone of CARETS
Estes, John E. (L4)	Land Use Investigations in the Central Valley and Central Coastal Test Sites, California
Kirvido, L. (L25)	Automatic Land Use Classification in Minnesota
Lundelius, M. A., C. Mark Chesnutwood, Joe C. Garcia, and R. Bryan Erb (L20)	A Comparison of Land-Use Determinations Using Data from ERTS-1 and High Altitude Aircarft
Miller, John M., and Albert E. Belon (L15)	A Multidisciplinary Survey for the Management of Alaskan Resources Utilizing ERTS Imagery
Place, John L. (L3)	Change in Land Use in the Phoenix (1:250,000) Quadrangle, Arizona, between 1970 and 1972, Successful Use of a Proposed Land Use Classification System
Raje, S., R. Economy, and J. McKnight (L18)	"First Look" Analyses of Five Cycles of ERTS-1 Imagery Over County of Los Angeles: Assessment of Data Utility for Urban Development and Regional Planning
Rehder, John B. (L10)	Geographic Applications of ERTS-1 Data to Landscape Change
Sattinger, Irvin J., and Robert D. Dillman (L21)	Digital Land Use Mapping in Oakland County, Michigan
Sellman, Buzz (L26)	Land Resources Survey for the State of Michigan
Simpson, Robert B. and David T. Lindgren (L12)	Land Use of Northern Megalopolis
Thompson, F. J. (L27)	Terrain Classification Maps of Yellowstone National Park

Todd, William J., Paul E. Mausel, and Kenneth A. Wenner (L19)	Preparation of Urban Land Use Inventories by Machine-Processing of ERTS MSS Data
Weeden, H. A., F. Y. Borden, N. Bolling, and Danielle N. Applegate (L17)	Investigation of an Urban Area and Its Locale Using ERTS-1 Data Supported by U-2 Photography
Welch, R. (L1)	Cartographic Quality of ERTS-1 Images
Westin, Frederick C. (L11)	Identification of Soil Associations in South Dakota on ERTS-A Imagery (paper L-11 is included in the summary under Agriculture, Forestry, Range Resources)
Wilson, A. David, and G. W. Petersen (L22)	Mapping of Agricultural Land Use from ERTS-1 Digital Data

Supplemental Program:

Wray, James R. (L7A)	Classifying Land Use in a Metropolitan Region by Digital Processing of ERTS-1 Multispectral Scanner Data
Wray, James R. (L12A)	Indications of Intra-Urban Environment of Washington, D. C. Interpretable from ERTS MSS Imagery

MINERAL RESOURCES, GEOLOGICAL STRUCTURE AND LANDFORM SURVEYS

Nicholas M. Short
NASA, Goddard Space Flight Center
Greenbelt, Maryland

The Mineral Resources, Geological Structure, and Landforms Analysis Session of the ERTS-1 Symposium was held on March 5 and 6, 1973. These papers were summarized by Dr. Laurence Lattman of the University of Cincinnati during the Thursday Summary Session of the Symposium. His summary paper appears in Volume II of the proceedings of the Symposium. A Working Group (whose members are listed in Appendix 1) met on March 9, 1973, to prepare a detailed summary of the session. The papers presented during the Mineral Resources, Geological Structure, and Landform Surveys Sessions of the Symposium are listed in Appendix 2.

This report is presented in four parts: Mapping Investigations, Dynamic Surface Processes and Landforms, Structural Elements, and Mineral Deposits within the broader session categories of Mineral Resources, Geological Structure, and Landform Surveys. A section outlining comments and conclusions by the Working Group follows these evaluations.

MAPPING INVESTIGATIONS

Summary of Significant Results

Science

In regions where rock exposures are good because of low vegetation cover, major geologic features such as folds; fault offsets; intrusion outlines; volcanic flows; contacts between distinctly different, thick rock units; and many landform types can be effectively mapped from ERTS images with details comparable to and sometimes superior to mapping by conventional aerial photo or ground methods. Corrections to existing maps are possible where tonal contrasts between units are definitive. To date, the broadest use of ERTS imagery in geologic mapping lies in construction of regional structural (or tectonic) maps.

Technology

Mapping from ERTS imagery at scales on the order of 1:250,000 is possible.

Computer-produced geologic maps at scales to possibly as large as 1:24,000 can be made with ERTS images with suprisingly good accuracy, provided training set data and other supervised methods are applied.

Winter imagery, involving foliage-free scenes or snow-cover enhancements, provides useful inputs for improved mapping in many instances. Such imagery is especially valuable in seasonally vegetated areas and areas with considerable relief.

Applications

In regions for which only poor quality or outdated maps have been produced, ERTS offers an excellent method for generating good general maps at small scales.

Mapping from ERTS in rugged, inaccessible regions, even in countries such as the U. S., where mapping programs are advanced, has some obvious advantages.

Maps prepared from ERTS data can usually be made in times less by an order of magnitude (or more) than by conventional methods; cost savings are potentially great but must await accuracy assessments.

Existing maps can be checked against ERTS imagery to correct mislocated or omitted rock unit contacts, geologic structures (fold axes, for example), lava flows, and so on.

New or improved small-scale geologic maps (for example, those showing regional landforms, Quaternary deposits in basins, sediment patterns, or distribution of lineaments) can be developed from ERTS images.

ERTS-generated maps depicting structural information (particularly lineaments) have utility in the search for ore deposits, oil accumulations, and ground-water zones. Applications to engineering geology (such as fracture zones encountered in tunneling; landslide potential, volcanic hazards) and seismology (recognition of lineaments associated with earthquake epicenters) are also promising.

Summary of Problem Areas and Limitations

Few quantitative studies have yet been made on the actual accuracy and correctness of interpretations of mappable data now being depicted on maps resulting from ERTS investigations; in other words, field checking has been insufficient to verify some of the claims being made.

In some instances, limitations in resolution have severely impeded some of the geologic interpretations being made from ERTS images.

Despite several implications to the contrary, no reliable identifications of lithologic types have been consistently made. Some exceptions include: recognition of basalts and other volcanics, and, occasionally, sandstones or shales. Such identifications often rely on the experience of the investigator in correlating with topographic expression or contextual patterns. Where various rock types can be compared in a scene with outcrops of known lithologies, training sets result that commonly can be extrapolated to other parts of the scene with reasonable reliability. But a technique for correctly identifying even the more general categories of rock types (for example, silicic, intermediate, and basic igneous rocks) using radiance data from the several ERTS bands has yet to be proven. The band ratio technique (MSS 7/5) leads to some enhancement of visual images that better separates rock types, but the ranges of ratio values for most common rocks and minerals overlap and thus do not give rise to unique spectral signatures by which notably different rock types can be distinguished (thus, the ratio interval for hematite and serpentine—two strikingly different minerals—is almost identical).

ERTS identification of stratigraphic units—by which the most common type of geologic map, showing age relationships, is produced—now seems almost impossible. Individual stratigraphic units are usually thinner than the linear resolution capability of ERTS (70-100 meters). Groupings of several similar-appearing units (light-colored, interbedded sandstones and limestones of different ages, for instance) are recognized as single units in many ERTS images (especially where the beds are steep dipping). These "remote sensing" units have some practical utility in outlining structural relationships, but their applicability to standard geologic mapping procedures is limited.

Assessment

ERTS imagery has been demonstrated to be usable in a variety of areas for general geologic mapping at scales about 12 times larger than that of the original (70mm) film, and even further enlargements retain most of the needed information. In poorly mapped, well-exposed areas, the imagery is being used for that purpose. However, the greatest value of this imagery is clearly in the production of regional structure maps, especially where fracture patterns can be delineated.

DYNAMIC SURFACE PROCESSES AND LANDFORMS

Summary of Significant Results

Science

Most types of higher order geomorphic units are exceptionally well displayed in ERTS images. The potential for producing regional, small-scale landforms maps—practically nonexistent for most parts of the world—is high, but still remains largely untapped by ERTS investigators.

The interrelationships between stream drainage systems and landforms are graphically illustrated by ERTS images.

ERTS may well be the ideal observational system for monitoring active glaciers, icecaps and their margins, and sea ice. Images in Alaska, the Arctic islands, and the Antarctic show the interactions of families of piedmont glaciers, their growth (surging glaciers can be recognized by their distinctive englacial moraine patterns), and their activities in supplying icebergs, meltwater, and so on.

Deposits from glacial advances—both Holocene and Pleistocene—are detectable on a regional scale. Moraines, drumlin fields, terraces, outwash plains, ice-flow markings, erosional features (cirques, aretes, "finger lakes," tarns) are visible together for the first time in expansive overviews (single frames or mosaics). Aspects of surfaces influenced by permafrost and tundra growth never before revealed over broad areas are evident in the ERTS images.

Characteristics of surfaces in deserts and semi-arid regions are readily examined from ERTS. Vast dune fields (often requiring multiple frame coverage) can be surveyed as a unit from ERTS, allowing correlations between field patterns and wind directions, topographic factors, and other surficial controls (for example, vegetation) to be made on a continuing temporal basis so that field migration can be followed and predictions developed for possible encroachments on human activities. Tonal variations in intermontane basins tend to correlate both with surface expressions of Tertiary and Quaternary rock units (and their soil derivatives) and with vegetation; definition of these deposits (which relate to the nature and history of basin-filling in a continental or subaerial environment) and their influence on landforms can perhaps be done to a detail not previously attempted.

Surveillance of regions undergoing active stream erosion will eventually allow some estimate of rates of change and damage to the land. ERTS can pick out the larger arroyos of Arizona that have been subjected to intensive erosion since 1890. An operational satellite system should be able to note expansion of such gullies if a sampling interval of years is selected.

Sedimentation studies in large lakes, estuaries, delta waters, and coastal waters can be carried out with repetitive ERTS coverage in a more effective manner than ever before.

ERTS affords an unexcelled opportunity to study large volcanoes and their effects on surrounding terrain. Such features as calderas, ring dikes, multiple flows, cinder cones, domes, necks, and ash-fall patterns are all readily resolved in ERTS images. The relationship of volcanoes to lineaments is especially highlighted by the regional coverage. The impact of an eruption, such as the recent one in Iceland, on its surroundings can be assessed during a continuing event and for periods thereafter.

The Data Collection System (DCS) has proved its worth in volcano monitoring. Already one volcano (Fuego in Guatemala) has registered signs of its impending activity on the instruments of an ERTS data collection platform, permitting prediction of an eruption that was then borne out.

Technology

Landforms definition is aided by the changing sun angles during seasonal coverage from ERTS. Certain features stand out during winter months at low sun angles. Desert regions and surfaces perennially covered by snow or ice are better imaged under certain lighting conditions.

The availability of several bands aids immeasurably in pinpointing some geomorphic features or processes. Landforms produced through the action of water are often emphasized in the near-infrared bands (for example, sinkholes in karst topography and glacial lakes). Glacial deposits usually show up to best advantage in Bands 6 and 7. Sand deposits are generally best revealed in Bands 4 and 7, but basin deposits are most easily delineated in Band 5. Bands 5 and 7 can be used to detect relative ages of volcanic flows because of tonal differences brought about by soil and vegetation. Distribution and densities of sediment load (and controlling currents) can be determined by comparison of all bands; Bands 4 and 5 are usually best, but where waters are choked with suspended matter, Bands 6 and 7 give additional information.

Applications

Glacial studies from ERTS will reap new benefits in searching for ground water in glacial drift (or in buried fractures), fresh water (in icecaps and so on), building materials (sands, gravels, clays), and sites that must meet certain engineering standards.

Active and stabilized dunes can be surveyed insofar as they may eventually influence man's activities.

Volcanic flows and ash deposits affect land use and, in particular, vegetation distribution and water supplies; these interrelations are often well displayed in ERTS images.

Sedimentation in estuaries and coastal waters affects shipping channels, fish distribution, and coastline erosion. The use of ERTS to establish changes in sedimentation supply and patterns will lead to interactions with these practical applications.

Mapping of regional landforms has useful implications for engineering and hydrology (location of dams, landslide monitoring, canal routing, runoff prediction, and so on) as well as for science (morphogenetic studies).

Summary of Problem Areas and Limitations

Presently, there is no good classification or map symbol system suitable for describing and recording landforms data at small scales.

Some dynamic processes require long periods of intermittent or discontinued monitoring in order to discern changes, whereas other processes require almost immediate coverages when abnormal changes (including catastrophes) occur. The fixed repeat cycle of ERTS does not always provide the optimum interval for surveillance. In this respect, a geosynchronous satellite has some obvious advantages.

Assessment

The value of ERTS for observing dynamic surficial processes that are constantly shaping and modifying the continents and their marine margins is unquestionably high. In many cases the synoptic and repetitive properties of the ERTS imagery will provide new perspectives to geomorphology that simply could not have been attained in any other way. ERTS is a singular instrument for assessment of certain kinds of short-term geologic phenomena. The geologic community would be well advised to take a hard look at ERTS imagery as a means for conducting geomorphic studies that should give fresh insights into both the basic understanding of the physical processes operating to sculpture the land and the beneficial applications such knowledge can bring.

STRUCTURAL ELEMENTS

Summary of Significant Results

Science

Folds and similar structural features are detectable with variable clarity on ERTS images. Success in detection depends on lithologic types and sequence (contrast effects), width of exposed sensible units, topographic expression, size of structure, structural setting (isolated or part of a fold system), degree of exposure, extent of ground cover (primarily vegetation), and sun angle. Examples of readily identified fold systems that make stricking appearances in ERTS imagery include the Central Appalachians, the Gaspe Peninsula, the Ouachita Mountains, the western Wyoming mountains, the Coast Ranges of California, the southwest Africa fold belt, the Atlas Mountains in Morocco, the Pyrennes, and the Zagros Mountains of Iran. However, some regions known from ground mapping for their structural complexities do not show up well in ERTS imagery in terms of fold expression; these areas include parts of New England, the Canadian Rockies, the Alps, and the Himalayas. Generally, small folds (up to 10 km) in basins such as those of Wyoming do not stand out sharply and probably little new can be learned about them (this implies a limitation to the use of ERTS as a means of locating small structures of interest in oil prospecting).

ERTS is proving exceptionally effective in bringing to light previously unrecognized circular structures. Many such structures of diverse origins are being spotted apparently as a result of the synoptic and illumination properties of ERTS images. Examples include circular to elliptical structures, volcanic or intrusive in nature, most likely in Nevada, Oregon, Missouri, New York, Brazil, and Ethiopia. Because ore deposits may be associated with such structures, discovery of new ones is significant. Many of the world's known impact structures, including Manicouagan, Ries Kessel, Flynn Creek, Crooked Creek, and Meteor Crater, are conspicuous in ERTS images. It can be anticipated that new impact structures will be found.

The most frequently reported achievement from ERTS of direct concern to geology is its ability to detect linear features on the earth's surface. These are recognized directly as distinct "lines" between tonally contrasted surfaces or indirectly as alignments of topography, streams, and so on. Some of these features are nongeological, such as power lines, roads, and animal migration routes, and so on, but many—perhaps the majority—are geological (including the following structural elements contacts, metamorphic grain, fractures, joints, faults, and a broad class called "lineaments" which can include any of the foregoing structural elements as well as other tectonic features of an indefinite nature, and the following geomorphic units: ice fractures, glacial flow markings, wind scour and depositional patterns, strand lines, and terraces) These linear features vary in scale and length from a few kilometers to regional or subcontinental dimensions. Many of the features correspond to previously known structural lineaments, but others are new or represent extensions of known lineaments. However, some known structural features are not expressed in ERTS imagery (probably because they were found from geological evidence observed in the field or in drill core but lack measurable surface expression at small scales).

A study of ERTS images of the Adirondacks led to this distribution of linears:

- Previously known: 232
- Known but not expressed on available images: 297
- New (unmapped): 329

Even in well-mapped areas of the world, new linears seen from ERTS can increase the mapped total by 25 to 50 percent or more under favorable circumstances. In remote, inaccessible, or poorly mapped regions (for example, ranges in Alaska and western Canada; the Andes; the Himalayas), the linears identified first in ERTS images may constitute the majority of those now known. In Wyoming, about 10 to 15 percent of the Wind River Range has been mapped for major fractures in an effort spread over the last five years; the remaining parts of those mountains were mapped at a comparable level of density and accuracy in three hours. A lineations map of a 34,000 square kilometer portion of the Canadian Shield was produced in 45 minutes because water-filled fractures stand out sharply in the infrared bands. In one case, the number of linears visible in ERTS images of southern Morocco exceeded by about 30 percent those found in the same areas using Gemini space photography.

Technology

Black and white transparencies are the best photographic products for detecting and examining structural features. Structural elements, particularly lineaments, are usually best defined in Band 5 imagery; if water is associated with a linear, it is commonly expressed as a prominent dark line in Band 7.

There seems to be a tendency for linears approaching a perpendicular orientation to the sun's rays to be especially enhanced by shadowing; those subparallel to the rays may be subdued in expression. If confirmed, this fact would lead to a preferential appearance of northeast-trending linears in ERTS images and a negative bias in the number of northwest-trending fractures.

Computer-controlled photographic enhancement of ERTS images and reprocessing of these images with special optical filters discloses many more linear features than are seen in the transparencies or prints. The VICAR program of the Jet Propulsion Laboratory, adapted to an ERTS image of northern Arizona, produced a graphic display in which the density of linears was greatly increased over those present in the photoimage.

Applications

From a scientific viewpoint, the improvement in our knowledge of larger, regional lineaments stemming from ERTS will lead to a resurgence in studies of regmatic shears and global fractures analysis and will likely add new insights and constraints in developing concepts of plate tectonics. Better defined patterns of fracturing of the crustal rocks, especially those patterns which appear controlled by the crystalline basement or those exposed in shields, will have important implications for reconstructing the stress fields (directions of compression, tension, shear) that are now operating or have acted in the past.

The economic and practical aspects of increased knowledge of regional structural elements—again principally recognition of new lineaments and definition of their distribution patterns—are numerous. Some ore deposits are controlled by or associated with lineaments or circular structures; recognition of new features, particularly intersections of lineaments, will provide new targets for mineral prospecting by other methods. Certain structures seen in fresh context from ERTS may require reassessment as potential traps for petroleum. Fracture zones and joints, expressed as lineaments, are frequently avenues of ground-water flow and storage. Many lineaments are also loci of active faulting, and hence sources of destructive earthquakes. Other lineaments may be potential hazards in engineering projects and could affect mining operations, tunneling, dam safety, construction on slopes, or loss of gas in storage.

A special benefit of linears detection from ERTS results from the ability to "see" such features in coastal plains, alluvial (intermontane) basins, glacial drift, and desert floors where these linears may be surface manifestations of a structural lineament present in bedrock at depth. These features tend to be subtly expressed and are frequently missed on the ground or in aerial photos.

Summary of Problem Areas and Limitations

So far, most of the linears reported by ERTS investigators have not been field checked as to their existence and causes. Many may prove to be spurious or improperly explained. Caution in claims made concerning the efficacy of ERTS as a linears detector is advised until enough of these features have been inspected and analyzed. Ultimately, a quantitative, statistical approach must be followed in verifying the reality and distribution of linears.

If linear features detected from ERTS are to be used in valid ways, then a genetic classification scheme involving working definitions and an eventual model for their nature, occurrence, and utilization must be developed before misidentified "lineaments" are oversold for the wrong uses.

Assessment

It is no surprise that the principal use of ERTS imagery for geological studies is in the definition of structural features exposed on the earth's surface. ERTS imagery is essentially an extension of high-altitude aerial photography insofar as applied to geological tasks. We should expect then that the images will be used in much the same way at first, at least until new techniques for feature recognition and data extraction are developed. Thus, mapping from ERTS is the most direct application. As stated earlier, conventional stratigraphic mapping is limited from ERTS because of the inability to resolve individual time-rock units and to identify lithologies. However, where thick, tilted marker units are present, fold relations can be specified irrespective of stratigraphic control. Currently, the detection of regional lineaments is yielding the biggest payoff from ERTS to geology.

MINERAL DEPOSITS

Summary of Significant Results

Science

Some investigators have cited the frequently used, but not verified, doctrine that mineral deposits (mainly metals) are commonly emplaced along faults and fractures and especially at intersections of faults and fractures, and have applied this concept to ERTS data. These investigations have plotted known mining districts or mineral occurrences on ERTS images in which new linears are also shown. In some instances, mines or quarries that heretofore were not associated with known structural controls appear to fall on or close to individual linears or intersection points. Examples given include base metals in the southwestern U.S., noble metals in Nevada, uranium and iron in Wyoming, and mercury deposits in California. These observations are still speculative at this time.

Some oil-bearing structures in California seem to be astride newly discovered linears; a structural control is thus suggested. Surface expressions of salt domes (major traps for petroleum) in the Gulf Coast region have been noted in ERTS images. Some depressions or upwarping, probably tied to such domes, are new features that warrant exploration.

Better definition of regional structures and surface expressions of intrusions known to be ore-bearing can lead to increased probabilities of finding new deposits. This has been proposed for an area in South West Africa and another in Pakistan, but actual exploration of newly mapped or remapped structures using ERTS images has yet to show that the potential suggested by their similarity to other nearby structures will be realized.

Only a few ERTS images have been searched for telltale surface coloration (blooms and gossan) that sometimes reveals alteration of certain mineral deposits. Results so far are negative, but a systematic effort to examine the surroundings of many active mines or blind ore deposits has yet to be made.

Some types of nonmetallic mineral deposits are probably amenable to prospecting from ERTS. These include sand and gravel deposits, building stone such as fresh granites, fire clays, and barite (associated with terra rosa).

Technology

Use of spectral information in the several ERTS bands to disclose evidence of chemical anomalies has been applied to detection of iron enrichments in Wyoming. A ratioing technique (MSS Bands 7/5) is employed to develop signatures for the common rocks and minerals in the region. The investigator claims to be able to discriminate an operating iron mine from the surroundings because the signature of hematite seems different from most other lithologic types in the area. Critical assessment of these results casts serious doubts on this claim.

Applications

One of the major selling points of ERTS has been its value as a minerals prospecting tool. In principle, this comes about from its ability to make or improve maps, better outline existing structures, identify new lineations, and relate these to subsurface controls, and recognize tonal anomalies that are physically or chemically caused by proximity to mineral concentrations. To a degree, each of these suggested capabilities is being realized in ERTS images, but their intrinsic value as guides to prospecting is yet to be demonstrated at the scales available from ERTS images.

Summary of Problem Areas and Limitations

The fundamental thesis of mineral deposit control by large lineaments is still only a general assumption. ERTS may provide a severe test of this approach by virtue of its ability to increase significantly the numbers of known lineaments that may or may not line up with mineral deposits or active mines. The ultimate test, however, will be the extent to which new deposits are eventually found along new linears or intersections.

The ambiguities of lithologic identification of major rock types extend also to ore deposits. Probably only iron oxide-related discolorations presently offer much hope of being detected from space. Color blooms from copper, cobalt, nickel, uranium and sulphur and other brightly colored effusives around volcanoes are usually too small and patchy in extent to be seen in space imagery, but exceptions should be sought.

Assessment

To date no new mineral deposits have been discovered by ERTS or other earth-observing satellites. The methodology for effective use of space imagery in mineral prospecting simply has not been developed. Some successes with aircraft remote sensing proves that such deposits can be found. ERTS images will probably be most valuable to prospecting through their use in improving our understanding of the tectonic framework of the earth's crust. However, ERTS is not likely to reach the status of geophysical or geochemical prospecting or drilling as the prime means of locating new mineral deposits.

WORKING GROUP COMMENTS AND CONCLUSIONS

Observations

- Results in geology from ERTS largely tend to be of an observational nature rather than explanatory or genetic
- Most geophysical and geochemical surveys take years to "pay off", ERTS should be allowed a similar time-line to prove its worth in geology.
- Bands 4 and 6 add little new information of geological value; other spectral regions (band intervals) should be considered
- Glaciated regions are particularly amenable to synoptic mapping from ERTS
- Tectonic mapping from ERTS is most effective at scales of from 1:250,000 to 1.500,000
- Linears discussed in the Symposium seldom were identified as to type or scale
- The regional or synoptic aspect of ERTS is the prime factor for discovery of so many new linears
- In the past, lineaments maps have not proved particularly useful in either theoretical or applied studies
- No rationale has been devised to explain why most lineaments are not mineralized but some are

Criticisms

- Many of the papers given in the Symposium showed obvious signs of prematurity, hasty preparation, and dependence on insufficient data and lack of field support—and should be judged within these constraints
- Too many claims about what ERTS can do in geology are being made without the support of careful scientific evaluation or statistical analysis
- Too many investigators are approaching their analyses and interpretations with an "air-photo philosophy"
- Many man-years of effort will be needed to test what has already been seen and reported
- Marine geological studies (including sedimentation) and glacial studies should be incorporated into the geological section rather than included in hydrology and oceanography

Program Deficiencies

- Many aspects of dynamic geology—including various short-lived phenomena—are not being examined by ERTS
- The present program has too few foreign studies. International programs should be emphasized
- There is an obvious lack of suitable map symbols for use in recording data on small-scale maps or in representing dynamic events and processes on maps
- There is a sparsity of investigations dealing with plains (flat-land) geology (that is, mid-continent and coastal plains), where ERTS offers some obvious advantages
- NASA needs to develop a workable and available quick-response capability (including image processing and aircraft support) to handle short-lived events (such as floods, fires, and earthquake damage)
- Training programs slanted toward the multidisciplinary approach are needed to acquaint geoscientists with and prepare them for effective use of remote information
- Future satellites and their support facilities should be designed to provide a greater proportion of near-real-time data
- The capabilities of DCP's for measuring geological phenomena are being greatly underutilized.

Recommendations

- Geological investigations that depend on, or lead to, predictive models should be given priority
- A program to study geological surface changes on longer-term cycles (for example, 10-year intervals) should be developed for future earth-observing satellites
- A rigorous procedural methodology for analyzing and using satellite data for geologic studies should be devised
- Digital reprocessing of ERTS data using enhancement techniques such as applied to Mars (VIC/R) should become routine
- An atlas of outstanding images of interest to geologists should be prepared
- Supervised digital (computer) mapping and feature extraction show great promise in geology and should be encouraged

- The team approach, in which the investigator works with many other specialists, needs to be promoted because of the vast areas presented in the individual (or mosaicked) scenes
- A separate study, using statistical tests, should be made to determine whether lineations actually are correlated with mineral deposits
- A data bank containing relevant geological information (earthquake epicenter locations, locations of mines, and so on) should become part of an earth resources program
- The use of stereo for geological work should be evaluated as a possible modification of sensor capabilities
- Any potential for earthquake predictions using ERTS data should be de-emphasized at this time, in the event that linears prove to have little relationship

APPENDIX 1

PARTICIPANTS IN ERTS-1 MINERAL RESOURCES, GEOLOGICAL STRUCTURE, AND LANDFORM ANALYSIS WORKING GROUP

John Bensko
NASA/Marshall Space Flight Center
Alabama 35812

David T. Gold
Department of Geosciences
The Pennsylvania State University
University Park, Pennsylvania

Robert S. Houston
Department of Geology
University of Wyoming
Laramie, Wyoming 82070

Yngvar W. Isachsen
Geological Survey
New York State
Museum and Science Service
Albany, New York

Laurence H. Lattman
Department of Geology
University of Cincinnati
Cincinnati, Ohio

Paul D. Lowman, Co-Chairman
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Michael McEwen
NASA/Johnson Spacecraft Center
Houston, Texas 77058

Larry Rowan
Geological Division
U. S. Geological Survey
Washington, D. C. 20244

Nicholas M. Short, Chairman
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Richard S. Williams, Jr.
EROS Program Office
U. S. Geological Survey
Washington, D. C. 20244

Frank Wobber
Earth Satellite Corporation
Washington, D. C. 20006

APPENDIX 2

PAPERS PRESENTED IN THE MINERAL RESOURCES, GEOLOGICAL STRUCTURE, AND LANDFORM SURVEYS SESSIONS

AUTHOR(S)	TITLE
Abdel-Gawad, Monem, and Joel Silverstein (G22)	ERTS Applications in Earthquake Research and Mineral Exploration in California
Allen, William H., and James A. Martin (G15)	"First-Look" Analysis of Geologic Ground Patterns on ERTS-1 Imagery of Missouri
Bechtold, I. C., M. A. Liggett, and J. F. Childs (G21)	Regional Tectonic Control of Tertiary Mineralization and Recent Faulting in the Southern Basin-Range Province (An Application of ERTS-1 Data)
Blodget, Herbert W., and Arthur T. Anderson (G5)	A Comparison of Gemini and ERTS Imagery Obtained Over Southern Morocco
Bodechtel, J. (G27)	New Aspects on the Tectonic of the Alps and the Apennines Revealed by ERTS-1 Data
Breckenridge, Roy M. (G14)	Glaciation in Northwest Wyoming as Interpreted from ERTS-1
Carter, W. D., and G. P. Eaton (G24)	ERTS-1 Image Contributes to Understanding of Geologic Structures Related to Managua Earthquake, 1972
Gedney, Larry (G23)	Some Aspects of Regional Tectonics in Alaska as Seen in ERTS-1 Imagery
Goetz, Alexander F. H., Fred C. Billingsley, Donald P. Elston, Ivo Lucchitta, and Eugene M. Shoemaker (G19)	Preliminary Geologic Investigations in the Colorado Plateau Using Enhanced ERTS Images

Gold, D. P., S. S. Alexander, and R. R. Parizek (G2)	Analysis and Application of ERTS-1 Data for Regional Geologic Mapping	
Gregory, Alan F. (G11)	Preliminary Assessment of Geological Applications of ERTS-1 Imagery for Selected Areas in the Canadian Arctic	
Hoppin, Richard A. (G31)	Structural Interpretations Based on ERTS-1 Imagery, Bighorn Region, Wyoming-Montana	
Isachsen, Yngvar V., Robert H. Fakundiny, and Stephen W. Forster (G1)	Evaluation of ERTS-1 Imagery for Geological Sensing Over the Diverse Geological Terranes of New York State	
Jensen, Mead L. (G3)	Geology of Utah and Nevada by ERTS-1 Imagery	
Lathram, Ernest H., I. L. Tailleur, and W. W. Patton, Jr. (G4)	Preliminary Geologic Application of ERTS-1 Imagery in Alaska	
McKee, Edwin D. (G8)	A Study of Morphology, Provenance, and Movement of Desert Sand Seas in Africa, Asia, and Australia	
Melhorn, W. N., and S. Sinnock (G25)	Recognition of Surface Lithologic and Topographic Patterns in Southwest Colorado with ADP Techniques	
Morrison, Roger B. (G7)	Application of ERTS-1 Multispectral Imagery to Monitoring the Present Episode of Accelerated Erosion in Southern Arizona	
Morrison, Roger B. (G13)	Mapping Quaternary Landforms and Deposits in the Midwest and Great Plains by Means of ERTS-1 Multispectral Imagery	
Pease, Robert W., and Claude W. Johnson (G33)	New Fault Lineament in Southern California	
Rich, Ernest I. (G18)	Relation of ERTS-1-Detected Geologic Structure to Ore and Mineral Fuel Deposits, Northern Coast Ranges, California	

Rowan, Lawrence C., and Pamela H. Wetlaufer (G20)	Structural Geologic and Radiometric Analysis of ERTS-1 Images of Nevada and Southern California: A Preliminary Report
Saunders, Donald F., and Gilbert E. Thomas (G30)	Evaluation of Commercial Utility of ERTS-A Imagery in Structural Reconnaissance for Minerals and Petroleum
Schmidt, Robert G. (G17)	Use of ERTS-1 Images in the Search for Porphyry Copper Deposits in Pakistani Baluchistan
Steffensen, R. (G28)	Structural Lineaments of Gaspe from ERTS Imagery
Viljoen, Morris J. (G26)	ERTS-1 Imagery as an Aid to the Definition of the Geotectonic Domains of the Southern African Crystalline Shield
Vincent, Robert K. (G16)	Ratio Maps of Iron Ore Deposits, Atlantic City District, Wyoming
Ward, Peter L., Jerry P. Eaton, Elliot Endo, David Harlow, Daniel Marquez, and Rex Allen (G9)	Establishment, Test, and Evaluation of a Prototype Volcano Surveillance System
Weidman, Robert M., David D. Alt, Richard B. Berg, Willis M. Johns, Raymond E. Flood, Jr., Katharine T. Hawley, and Linda K. Wackwitz (G32)	Applicability of ERTS-1 to Lineament and Photogeologic Mapping in Montana—Preliminary Report
Williams, Richard S., Jr. (G10)	Satellite Geological and Geophysical Remote Sensing of Iceland—Preliminary Results from Analysis of MSS Imagery
Withington, Charles F. (G29)	Lineaments in Coastal Plain Sediments as Seen in ERTS Imagery
Wobber, Frank J., and Kenneth R. Martin (G12)	Exploitation of ERTS-1 Imagery Utilizing Snow Enhancement Techniques

ENVIRONMENT SURVEYS

Louis S. Walter
NASA, Goddard Space Flight Center
Greenbelt, Maryland

INTRODUCTION

The Environment Surveys Working Group met on March 9, 1973 (a list of participants is given in Appendix 1). The group established two ground rules to give direction to its effort:

- Consideration would be given to all relevant papers, not only those papers presented during the Environment Surveys sessions of the ERTS-1 Symposium
- Our assessment would be critical—we would try to evaluate areas in which remote sensing fails as well as those in which it is useful

To this end, this report sets forth the Working Group summary: Symposium results, our evaluation of these results, and the further requirements of environmental investigators. A list of Environment Survey papers, as well as related papers from other sessions, appears in Appendix 2.

BACKGROUND

The field of environmental quality, because of its multidisciplinary nature and its relatively recent definition of a separate field of study, must first be defined before one can begin to assess the accomplishments within its scope. This was the initial task of the working group. With this caveat in mind, the group adopted the following operational definition: *Environmental quality* is restricted to the study of air, water, and land pollution and, in particular, the pollution which is caused by man and his works. Many of the effects being investigated in other discipline areas relate intimately to our interests; for example, the harvesting of trees may give rise to accelerated erosion, which then gives rise to stream pollution. Therefore, the work in this discipline will continue to be coupled with peripheral investigations.

The next task before the group was the definition of the major problem areas facing the discipline of environmental quality. This was necessary in order to provide a basis for establishing the degree to which ERTS-1 has been effective in attacking problems in environmental quality. The following categorization of problem areas was adopted:

- Air pollution

  Mobile sources (for example, automobile emissions), gaseous
  Stationary sources (for example, industrial), gaseous, particulates, odors
  Fires

- Water pollution

  Sedimentation (erosion)
  Domestic/municipal waste disposal
  Industrial wastes (chemical, mineral, biological, thermal)
  Agricultural (pesticides, salts, sedimentation)
  Oil spills, ocean dumping

- Land pollution

  Solid waste disposal
  Mineral exploitation (strip mines, tailing piles)
  Agricultural (abandonment, pesticides, erosion)
  Forestry (cutting practices, erosion)
  Construction (denudation, erosion, slope changes)

- Aesthetics

  Urban sprawl, unplanned development
  Highway construction, billboards
  Dumping sites
  Encroachment into natural preserves
  Noise

This list represents some of the major areas of concern in environmental quality. In accordance with our definition of the field, we have restricted our interests so as not to encroach upon problems (for example, floods, earthquakes, and so forth) which are primary concerns of related disciplines such as hydrology and geology.

SYMPOSIUM RESULTS

We have considered the Symposium results along the lines established in defining the problem areas. While these limits serve as an outline for the subsequent discussion, they are not coincident with the session and papers in Environmental Quality. As a result of the interdisciplinary nature of this field, many significant applications were reported in papers delivered in other sessions. The Working Group, therefore, deliberately attempted to be catholic in its attendance, its evaluation, and its consideration of the results reported herein.

Air Pollution

The spectral and spatial resolution of the ERTS-1 sensors has permitted us to monitor and assess some specific sources of air pollution. The ability to detect emissions, generally from industrial sources, has been demonstrated by Copeland and Sweet. Copeland demonstrated the use of density slicing in the identification of smoke plumes. In this work it was possible to detect previously unreported emission sources leading to possible law-enforcement applications. Lyons also identified smoke plumes over Lake Michigan and related their occurrence to nucleation in snow showers. On a broader scale, atmospheric aerosol content and haze have been studied, primarily with regard to their effect on the deterioration of signals from the earth's surface. The paper by Griggs tended to relate such a study to environmental problems. Several investigators reported the observation of the condensation trails from high-flying aircraft.

Water Pollution

Lind has used ERTS imagery to detect the chemical discharge from a paper mill into Lake Champlain. This information, along with numerous aircraft photographs, is being used in court by the State of Vermont to affect a cease and desist order against the polluter located in New York State.

Many investigators were able to detect sediment (or turbidity) in rivers and streams using ERTS imagery. For this purpose, MSS Band 5 was found particularly useful. Differences in sediment content within rivers, bays, lakes, and reservoirs were easily discernible. Yarger assessed the turbidity of major reservoirs in Kansas and showed that suspended load measurements were in good agreement with tonal variations in the MSS imagery. In Cook Inlet and in the Vancouver, British Columbia area, for example, sediment plumes were useful in delineating major circulation patterns. Yarger mapped the Long Island Sound sediment plumes from the Connecticut River over several tidal cycles. These data were used in the analysis of the river's impact on pollution in the area.

The demonstration of the detection of the dumping of industrial wastes in the oceans has been made quite effectively in the papers by Mairs, Wezernak, and Fontanel. The wastes discussed in the first two papers are carried to the New York Bight by barges and intentionally dumped in predefined areas selected so as to avoid environmental contamination of the shoreline. It is now possible to monitor the location of dumping to assure compliance with the regulations. Wezernak also reports the detection of municipal waste disposal in the bay and ocean east of New York City. Klemas, investigating turbidity in the Delaware Bay, identified areas in which wastes could be concentrated because of currents. Areas such as these must be avoided as dumping sites.

The nearshore environment was the subject of several papers. Rate and extent of beach erosion can be evaluated through study of coastal circulation dynamics as in the papers by

Slaughter and Mairs, although major long-term changes in shoreline configuration were actually measured from the images by Kerhin. The monitoring of coastal and interior wetlands was the subject of several papers (Anderson, Carter, and McGinness; Klemas and Bartlett; Brown, Meyer, Ulliman, Prestin, Trippler, Gamble, and Eller; Clapp, Kiefer, McCarthy, and Niemann). Attempts were made to map the general plant communities, boundaries, and areas impacted by man-related activities. Anderson claimed that plant communities could be mapped to a scale of 25 meters and felt smaller units could be identified but not accurately placed.

The detection of algal blooms and red-tide encroachment on fresh and saline bodies was noted by Gilbertson and Jensen. The size and movement of these "growths" would seem to make them ideal targets for monitoring from ERTS.

Land Pollution

Strip-mine and mine-dump investigations were reported by several investigators. Studies by the Indiana Geological Survey (Wier, Wobber, Russell, and Amato) related to the detection of hazards pertinent to underground mines led also to updating of maps of lands disturbed by the strip mining of coal. Areas of less than five acres could not be mapped. Ohio investigators (Chase and Pettyjohn; Sweet, Wells, and Wukelic) reported the determination of an increase in the acreage of disturbed land through the comparison of maps made using ERTS computer-compatible tape data with other maps made from air photos taken a year earlier. Efforts were also made to determine the extent of the reclamation or revegetation of strip-mined areas. This was also true for investigation of strip-mine practices in Pennsylvania (Alexander, Dein, and Gold; Saltinger and Dillman) in which digital processing of ERTS data permitted the identification of strip mines not discernible in the imagery.

In South Africa, imagery was employed to monitor revegetation of mine dumps (Gilbertson). Open mines were also studied using ERTS data in Tennessee (Rehdler), the Cumberland Plateau (Breckenridge, Marrs, and Murphy), Wyoming (Lundelius, Cook, McGuigan, Tunnell, and Bennett), and Minnesota (Brown, Meyer, Ulliman, Prestin, Trippler, Gamble, and Eller).

EVALUATION OF RESULTS

In our estimation, the results presented at the Symposium show that the ERTS system is capable of some contributions in the field of environmental monitoring. In selected areas, especially in the detection of soil denudation and the assessment of strip mining and reclamation efforts, direct and immediate application has been demonstrated. The Working Group had the impression, comparing the results discussed in this summary with the spectrum of problem areas presented here in the introduction, that the present satellite system is contributing to solutions in 1 to 20 percent of the areas. Since we attempted to weight the problem areas according to their significance, the variation in our assessment reflects a variation in the evaluation of the significance of the problems which the ERTS system tends to treat as well as varying impressions as to the efficacy with which the system helps in alleviating the problems.

Air Pollution

The ability of satellite remote sensing to detect particulates from point (industrial) and mobile (aircraft) sources has been demonstrated. However, gaseous pollution (automobile) has not been discussed directly.

Water Pollution

The ability of the system to estimate and map large-scale turbidity in rivers and oceans has been demonstrated. On this scale, water pollution from domestic, municipal, and industrial sources has also been observed, if not quantified. On this subject, it is pertinent to note that, in the case of dumping of industrial wastes in the New York Bight, the constituent of the waste which permits detection appears to be iron sulphate, which occurs in the waste material at a concentration of approximately 10 percent. However, the investigation did not investigate the properties of the waste which enabled detection. It is thus difficult to extrapolate the findings from these investigations to other circumstances. The superficiality of treatment is typical of many of the areas investigated and points up the need for more penetrating investigation.

In addition, while ERTS investigations were able to detect algal blooms, there have been, to date, no reported observations of oil spills, and pollution originating from diffuse sources (for example, agriculture/pesticides) has proven difficult or impossible to observe, even qualitatively.

Land Pollution

In this area, more than any other, the limitation imposed by the spatial resolution of the system is apparent. The results reported concern only those large-scale problems in land pollution which result from man's larger modifications to the landscape, such as strip mines, tailing piles and denudation resulting from projects such as highway construction and forestry. Many of the sources with dimensions in the range of several hundred meters have not been efficaciously treated through ERTS. For example, areas of solid-waste disposal and denudation resulting from construction sites are often on too small a scale.

REQUIREMENTS IMPOSED BY APPLICATIONS IN ENVIRONMENTAL QUALITY

The current limitations on the utilization of the ERTS-1 data are imposed by the spectral, spatial, and temporal resolution of the system. Of these, the spectral resolution requirements are most difficult to evaluate, in part because of the extremely complex variations of the spectral response of materials and the effects of atmospheric absorption. In this area, we can only suggest that a compilation of spectral data is a basic requirement for environmental-quality applications; that such basic data should also consider features such as the iron-sulphate dissolved in ocean-dumped wastes which renders the wastes observable.

It has been demonstrated that the ability to detect atmospheric pollutants is limited because variations in spectral response due to variations in atmospheric constituents is overwhelmed by variations in the spectral response of the background. Consequently, such pollution is readily identifiable only over homogenous backgrounds such as the Great Lakes. Furthermore, the variations in spectral response due to the presence of gaseous contaminants are small compared with the levels of differentiation of the energy levels in the on-board data processing, which detracts from our ability to assess the degree or even the presence of gaseous air pollution.

We recommend consideration of the possibility of increasing the ability of the system to discriminate between finer energy levels in the recorded spectra.

The Working Group feels that improvement in spatial resolution would be more rewarding in the field of environmental quality than in most other disciplines covered by ERTS investigations. In relative terms, if the resolution were increased by one-half an order of magnitude (to 20 meters), we estimate that the environmental benefits would be increased by several orders of magnitude. For example, this improved resolution would permit the detection of smaller areas of denudation and siltation sources which are much more prevalent than those currently observed. Present resolution capability allows the detection of only large-scale sources of water pollution. Increased resolution would permit the identification of the numerous small sources which probably represent a more significant portion of the contributors to water pollution.

While the ability of the system to detect the results and even the sources of environmental pollution has been demonstrated or (as in the case of oil spills) should be achievable, the infrequent coverage which the present system permits is of serious concern. Many of the events of significant impact in our discipline have occurrences or durations which are short in comparison with the 18-day cycle which ERTS offers. There are many examples: oil spills, forest fires, turbidity resulting from storms, and so on. Furthermore, in the area of environmental monitoring, there are several environmentally adverse practices (including stack emissions and ocean dumping) which, given the long repeat cycle and predictability of coverage, can be timed so that digressions from acceptable practice can be phased so as to be undetectable. Satellite coverage at greater frequencies could make such practices uneconomical.

In general, we wish to point out that the utilization of data from the ERTS system is predicated upon a large user community; that the usefulness of these data at the operational levels is, in turn, based on the nature of the products which can be delivered. For this reason, we suggest that the use of computers in the manipulation and integration of the ERTS data will prove particularly important. We feel that the most important results presented herein have generally been based on the regeneration of the data, generally from computer compatible tape, through digital means which permits and allows more quantitative treatment and, consequently, results which are more immediately applicable.

APPENDIX 1

PARTICIPANTS IN THE ERTS-1 ENVIRONMENT SURVEYS WORKING GROUP

Dr. David Bowker
NASA, Langley Research Center
Hampton, Virginia 23365

Dr. Virginia Prentice
Environmental Research Institute of Michigan
Ann Arbor, Michigan 48104

Dr. Charles Schnetzler
NASA, Goddard Space Flight Center
Greenbelt, Maryland 20771

Dr. Louis Walter, Chairman
NASA, Goddard Space Flight Center
Greenbelt, Maryland 20771

APPENDIX 2

PAPERS PRESENTED IN ENVIRONMENT SURVEYS

AUTHOR(S)	TITLE
Alexander, S., J. Dein, and D. P. Gold (E3)	The Use of ERTS-1 MSS Data for Mapping Strip Mines and Acid Mine Drainage in Pennsylvania
Anderson, Richard R., Virginia Carter, and John McGinness (E7)	Atlantic Coast Wetlands Mapping (Maryland, Georgia) Using ERTS-1 Imagery
Breckenridge, Roy M., Ronald W. Marrs, and Donald J. Murphy (L13)	Remote Sensing Applied to Land-Use Studies in Wyoming
Brown, Dwight, Merle P. Meyer, Joseph Ulliman, Steven Prestin, Dale Trippler, James Gamble, and Ralph Eller (L14)	ERTS-1 Applications to Minnesota Land-Use Mapping
Chase, Phillip E., and Wayne Pettyjohn (E2)	Determine Utility of ERTS-1 to Detect and Monitor Area Strip Mining and Reclamation
Copeland, G. E., A. R. Brady, Earl C. Kindle, and Gary Hilton (E5)	Remote Detection of Aerosol Pollution by ERTS
Fontanel, A., J. Guillemot, and M. Guy (R6)	First ERTS-1 Results in Southeastern France: Geology, Sedimentology, Pollution at Sea

Gilbertson, Brian (E4)	Monitoring Vegetation Cover on Mine Dumps with ERTS-1 Imagery: Some Initial Results
Kerhin, Randall T. (M2)	Recognition of Beach and Nearshore Depositional Features of Chesapeake Bay
Klemas, V., and D. Bartlett (E8)	Identification of Coastal Vegetation Species in ERTS-1 Imagery
Klemas, V., R. Srna, and W. Treasure (M3)	Applicability of ERTS-1 Imagery to the Study of Suspended Sediment and Aquatic Fronts
Lind, A. O., E. B. Henson, J. O. Pelton (E11)	Environmental Study of ERTS-1 Imagery: Lake Champlain and Vermont
Lundelius, M. A., V. L. Cook, D. P. McGuigan, S. H. Tunnell, and W. P. Bennett (L20)	A Comparison of Land-Use Determinations Using Data from ERTS-1 and High Altitude Aircraft
Lyons, Walter A., and Steven R. Pease (W17)	ERTS-1 Views the Great Lakes Area
Mairs, Robert L., Frank J. Wobber, and Donald Garofalo (E9)	Application of ERTS-1 Data to the Protection and Management of New Jersey's Coastal Environment
Rehdler, John B. (L10)	Geographic Applications of ERTS-1 Data to Landscape Change
Saltinger, Irvin J., and Robert D. Dillman (L21)	Digital Land-Use Mapping in Oakland County, Michigan
Schubert, J. S., and N. H. Mac Leod (E13)	Digital Analysis of Potomac River Basin ERTS Imagery: Sedimentation Levels at the Potomac–Anacostia Confluence and Strip Mining in Allegheny County, Maryland

Slaughter, Turbit H. (M1)	Seasonal Changes of Littoral Transport and Beach Width and Resulting Effect on Protective Structures
Sweet, David C., Terry L. Wells, George E. Wukelic (R3)	Resource Management Implications of ERTS-1 Data to Ohio
Takakazu, Maruyasu, and Tsuchiya Kiyoshi (E14)	Present Status of Remote Sensing with ERTS Imagery in Japan
Wezernak, C. T., and N. Roller (E10)	Monitoring Ocean Dumping with ERTS-1 Data
Wier, Charles E., Frank J. Wobber, Orville R. Russell, and Robert V. Amato (E1)	Fracture Mapping and Strip Mine Inventory in the Midwest by Using ERTS-1 Imagery
Wightman, J. M. (E6)	Detection, Mapping and Estimation of Rate of Spread of Grass Fires from Southern African ERTS-1 Imagery
Yarger, H. L., and J. R. McCauley (E12)	Water Turbidity Detection Using ERTS-1 Imagery

WATER RESOURCES

Vincent V. Salomonson
NASA, Goddard Space Flight Center
Greenbelt, Maryland

INTRODUCTION

On the last day of the ERTS-1 Symposium, March 5-9, 1973, a small group composed of participants and attendees at the ERTS-1 Symposium gathered to exchange observations as to the significant results reported during the many presentations and to discuss the areas that need further emphasis in future ERTS-1 data analysis efforts. The personnel attending the session had wide familiarity with activities going on in remote sensing and water resources and in certain cases, some responsibilities at NASA centers for maintaining cognizance of achievements and appropriate directions for further research activities. The list of personnel attending is given at the end of this report (Appendix 1). The following pages summarize the accomplishments noted at the ERTS-1 Symposium in the Water Resources Sessions with some additional references to results reported in other sessions. A list of the papers referred to in this summary is given in Appendix 2.

LAND USE AND GEOLOGY

Significant Results

Various land uses related to water resources management can easily be identified and mapped using ERTS-1 data at a scale of 1:250,000. By noting the location and areal extent of these various land uses, the sources of water pollution increasing sediment load sources and changing water yield can be delineated. In general, topographic maps do not possess the kind of dynamic hydrologic information available from the repetitive coverage of ERTS-1. In addition, single ERTS-1 images offer more information than available on these topographic maps. Stream channel development and network, stream length, and the location of ponds and lakes can be mapped from ERTS-1 at a scale better than 1:250,000. These conclusions are supported by the results presented by several authors at the symposium (Stoertz and Carter; Espejo, Torrent, and Roquero; and Van Liere). ERTS-1 detection of geologic fracture zones and especially intersections of fractures has potential for the additional development of groundwater resources. It has been shown that potentially high yield groundwater wells can be drilled along these fracture zones (for example, Gold, Alexander, and Parizek). It appears that ERTS-1, by mapping regional fracture zones, will aid in regional groundwater development in Pennsylvania which previously was not possible.

Areas Needing Further Research

For further research efforts, it is suggested that there be increased use and an accurate definition of the applicability of ERTS-1 land use and physiographic information in statistical and deterministic models for runoff prediction and hydrologic cycle studies. In particular, ERTS-1 land use and physiographic data should be used to estimate mean annual flow and flood for ungaged watersheds (see Hollyday, for example). In addition, although it has been shown that ERTS-1 can effectively map hydrologic features on a scale of 1:250,000, it is apparent that useful mapping can be conducted at considerably larger scales. As a result, there should be improved definition of ERTS-1 mapping scale limits for hydrography and the charting of hydrologically relevant land uses.

FLOOD PLAIN AND FLOOD INUNDATION MAPPING

Significant Results

The mapping of flood inundated areas was one of the most striking of the hydrological applications of ERTS-1. In two cases, the East and West Nishnabotna Rivers in Iowa (Hallberg, Hoyer, and Rango) and the Gila River in Arizona (Morrison), it has been shown that the areas inundated by flooding can be mapped at scales of 1:250,000 or larger. In both of these cases it was shown that the flood boundaries mapped from ERTS-1 corresponded closely to low altitude aerial mapping of the flooded areas. Using the 0.8-1.1 μm near infrared band, the effects of the flood could be mapped from 7-12 days after the event. In the Iowa flood, ERTS-1 allowed flood mapping to be extended to large data-sparse areas. Sequential imagery following the Gila River flood permitted observation of the drying out of the flooded area. A similar progression of drying was noted in the Sacramento River Delta after flooding of Andrus Island due to a break in the levee system (Burgy). In these cases, it appears that the 18-day cyclic coverage of ERTS-1 is not as much of a handicap as previously envisioned. A 10-day coverage cycle would probably be sufficient in many flood situations.

Areas Needing Further Research

Areas for further emphasis include mapping of the flood plain prior to flooding for flood plain zoning purposes. Indicators for such mapping may include physiographic characteristics, channel configuration, soil and vegetation differences, agricultural patterns, and land use boundaries. Short-term flood potential may be delineated by ERTS-1 observations of saturated soil moisture conditions in low-lying areas. Efforts should be made to map occasional floods to better define ERTS-1 flood mapping capabilities in regard to flood recurrence intervals of 10, 50, and 100 years. The utility of digital data manipulation and enhancement techniques should be explored for use in improving mapping of flood inundation and flood plain characteristics. Finally, most flood mapping has been performed in late summer in a few isolated areas. The success of flood mapping should be investigated in other seasons and for other regions in order to assess the applicability under a variety of situations.

SNOW-COVER MAPPING

Significant Results

Because of its high reflectance, snow cover has proven to be readily identifiable under cloud-free conditions. When clouds are in an ERTS-1 scene they can usually be distinguished in mountainous regions from snow because of pattern differences involving the characteristic dendritic structure of the watersheds covered by snow. Under optimum conditions it has been found that the elevations of the snow line can be estimated to the nearest 60 meters (Meier). It has been found that more detail can be obtained from the ERTS-1 snowline information than is commonly obtained in operational aircraft surveys in the Verde Salt River Watershed in Arizona (Barnes). Furthermore, the time to obtain a survey of the snowline in this area from ERTS-1 is about two hours. The time required to analyze an ERTS image is very comparable to the time required to analyze the information gathered during an aircraft survey. In the Thunder Creek Watershed in the Northern Cascades of Washington, it has been found that snow covered area can be estimated from ERTS to within 4% of the snow covered area or 1% of the watershed area (Meier).

Areas Needing Further Research

Changes in snow covered area have been related to measured runoff for one season. The results indicate a good relationship and suggest that this is a viable approach for runoff prediction. More work to substantiate and extend this approach to other areas needs to be done.

Results so far indicate that there are some noteworthy difficulties in mapping snow in terrain covered by heavy vegetation. Other factors such as shadows and highly reflecting rocks oriented at angles nearly perpendicular to the sun may cause misidentification problems. In order to overcome these problems effectively, some familiarity with the area is required. It certainly appears that if automated and/or digital objective techniques are to be employed, separate approaches for vegetated versus non-vegetated areas are going to be required for the mapping of snowcover. An additional facet of snow cover mapping which has not been explored satisfactorily as yet is ERTS-1 imagery for extending in-situ point measurements of snow depth and moisture to other points within a given watershed.

Another area which has been examined in the past using Nimbus 3 HRIR 0.7-1.3 μm data concerns the mapping of areas where snow or ice is melting. The presence of a thin film of water from melting lowers the reflectance of the surface considerably. If areas within an entire snowfield can be delineated as melting areas, this, undoubtedly, would be useful information in runoff forecasts (note the use of the DCS for this purpose in the paper by Schumann). More examination of the 0.8-1.1 μm data over snowfields is in order to see how well this kind of occurrence can be observed and applied.

GLACIER OBSERVATIONS

Significant Results

The ERTS-1 satellite has provided those persons interested in glaciology with a new and exciting observational tool. Not only does ERTS-1 offer wide area observations over remote regions, but the multispectral, relatively high spatial resolution, repetitive coverage has permitted the observations of medial moraines, unusual glacier surges or movements, snowlines and other somewhat more subtle features. Surging glaciers such as the Bering Glacier on the southern coast of Alaska and the Yentna Glacier can be distinguished from non-surging glaciers by the relatively wiggly-folded moraines that are quite apparent in ERTS-1 observations (Meier). The snowlines on the glaciers can be observed to change position from one satellite pass to another.

Areas Needing Further Research

Inasmuch as the snowlines are responsive to climate and the heat budget over the glacier, the mean positions of snowlines can serve as clues to the accumulation - area ratios and mass balance of the glaciers. Studies of this glacier characteristic need to be continued or initiated over many glaciers.

As was the case with snow, the 0.8-1.1 μm observations can delineate areas on the glacier that are undergoing melting. This melting should produce melt water runoff and subsequently affect lakes and streams below the terminus of the glaciers. In Southern Alaska streams coming from glacier melt have created large sediment plumes extending into the Gulf of Alaska for tens of kilometers. The extent of the plumes and the extent of melting on the glacier should provide new information about melt rates and runoff volumes in areas not presently providing any or sufficient conventional observations.

Because snow and glaciers have relatively high reflectance (which permits ease of observation) and ERTS-1 provides world-wide coverage, it would appear the time is ripe for making measurements of the global areal extent of snow and ice cover and even its seasonal variation. Certainly these observations would be very exciting insofar as the relationship to global fresh water availability and global climate is concerned. This is particularly true in view of the fact that it is estimated that 80% of the world's fresh water is stored in the glaciers.

DATA COLLECTION SYSTEMS

Significant Results

The Data Collection System (DCS) on ERTS-1 has proven in several instances to date to be a reliable and rapid means of collecting and relaying hydrologic data so that they can be used in operational water resources management situations requiring near real-time data. DCS operation on the Verde River Watershed in Arizona (Schumann) has shown the ability to accurately construct streamflow hydrographs and supply timely snowmelt runoff information to the Salt River Valley Water Users Association. During a critical snowmelt period in which conventional data relay capabilities had failed, ERTS-1 was able to relay streamflow data to the users within one half hour of actual measurement. Reservoir water release was controlled with this information and road closure and inconvenience from excess flood waters was reduced considerably. In the Northeast, data from 20 stations measuring water quality, streamflow, and groundwater information are being collected and relayed from the Delaware River watershed via the ERTS-1 DCS to the Delaware River Basin Commission in near real-time (Paulson). By conventional means, the receipt of these data would take weeks. In Florida the data collection system is being used to collect water level and rainfall information (Higer, et al.). When coupled with ERTS-1 imagery of the same area, the DCS now permits volumetric estimates of existing water to be made for the first time since the U.S. Congress established the Central and Southern Florida Flood Control Act in 1947. In general the data collection system has been proven reliable when placed in remote and/or severe environments.

Areas Needing Further Research

Certain areas for exploiting the data collection system capability should be explored. Tape recorder storage on satellites for the DCS data should be considered to promote world-wide coverage, particularly in conjunction with the International Hydrological Decade activities and beyond. In addition, improved data storage capabilities on the ground would be useful so that the satellite could relay data taken over a longer time period rather than just at the time of overpass. It also appears that the capability for direct readout of the DCS information that has been relayed to the satellite could profitably be used by agencies such as the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, and the U.S. Geological Survey. Finally, further use of DCS lake or reservoir stage information combined with imagery estimates of surface water area should be made so that volumetric estimates would be available on a more frequent basis.

SURFACE WATER AREA

Significant Results

As noted earlier in this report, surface water is the most easily distinguished theme in the 0.8-1.1 μm observations. Surface water bodies as small as 1 hectare in size can be located in imagery and rivers as narrow as 70 meters can be easily followed. This capability has been used to measure the areal extent and changes with time of surface water areas covering thousands of square kilometers (for example, Baumgardner and Reeves). The appearance or disappearance of features surrounding lakes or reservoirs such as Folsom Reservoir in Northern California (Burgy) can be used to indicate the water level. As noted in the previous section, it is possible to combine the area information from imagery with stage information (such as that obtainable using the Data Collection System) and some bottom topography information, and obtain useable volumetric relationships.

Areas Needing Further Research

It was noted that the volume of water in lakes or reservoirs is more important than area information so other means applicable to remote, unsurveyed, or inaccessible regions, need to be explored to estimate volume. One possible means of doing this would be to establish area-volume empirical relationships that apply in well-defined physiographic regimes. This could be done in a well-known region and then applied to other similar remote regions. Another area which needs more emphasis and research where shallow water bodies exist is the possibility of utilizing the bottom-viewing capability in the 0.5-0.6 and 0.6-0.7 μm bands to arrive at volumetric estimates when used in combination with the areal extent information available most readily in the near infrared bands. Surveys involving the measurement of surface water area over wide regions such as continents or the globe would provide measurements of scientific and practical interest. The amount of water subject to evaporation, the nearness of population centers to available water supplies, and more accurate indices of the total water available for human consumption and its change with time could be much more accurately and rapidly obtained.

WETLANDS MAPPING

Significant Results

The mapping or monitoring of surface water is rather closely tied to the mapping of wetlands. However, the expression of vegetation and soil moisture along with standing surface water must be understood in order to usefully delineate wetlands. Concerning coastal wetlands, it was reported during the Symposium that many important details such as marsh-water interface, upper wetland boundary, and plant communities consisting of Spartina alterniflora (salt marsh cord grass), Spartina patens (salt marsh hay), for example, can be mapped reliably on the 1:125,000 map scale (Anderson, Carter, and McGinnis; Klemas and Bartlett; Mairs, Wobber, and Garofalo). Using digital data the areal extent of wetlands was objectively mapped with accuracies between 86 and 99% (Flores, et al.). In some cases relevant features were mapped on scales as large as 1:24,000 but here pertinent boundaries become quite blurred. The ERTS imagery has been used as informational products in New Jersey to assist the state in management of its coastal resources. Marshes, sloughs, and small ponds in inland areas can also be monitored. Results were presented from the Yukon-Kuskokwims Delta area and for areas in North Dakota (Van Tries; Gilner and Klett).

Areas Needing Further Research

In view of the fact that wetlands constitute a very valuable recreational and environmental resource, it would seem important that efforts to monitor wetlands be continued and improved wherever possible so that the imagery can be reliably used to supplement or extend conventional surveys. As these advancements are made, it would be particularly important to interact with interested parties such as state governments so that they will see fit to apply this data source as soon as possible for better wetlands management and supervision.

WATER QUALITY

Significant Results

One of the most intriguing aspects of ERTS observations is the reflectance variations readily observable in water bodies from ERTS-1. These reflectance variations are due largely to variations in depth, suspended sediments, concentrations and pollutants, and/or biological activity of various kinds. These variations have been repetitively observed over rivers and water bodies, particularly in the 0.5-0 6 and 0.6-0.7 μm observations. Representative results pertaining to Lake Ontario were reported by several authors (Falconer, et al.; Wagner and Polycn; and Pluhowski). Other results concerning turbidity in Tampa Bay and algal mats in Utah Lake and Lake Erie were reported by Coker, et al., and Strong, respectively. The turbidity patterns at a given time have been qualitatively found to be associated with the discharge of rivers into larger lakes and to circulations within the lakes themselves and shorelinc erosion processes. Changes in the extent and shape of these patterns have been inferentially related to variations in wind flow direction (air-water interaction) and drainage variations in rivers. The algal mats were observed in much more detail and clarity than conventional observations in the visible portion of the spectrum had ever revealed.

Areas Needing Further Research

The eighteen day repetitive coverage afforded by ERTS-1 is considerably less than optimum for the study of plume dynamics. Nevertheless, the extent and location of these patterns at any given time do deserve study and do offer valuable guideline information as to where benchmark in situ observations might most appropriately be located. So far, this latter suggestion has not been tried to any apparent extent. The circulation features shown in the imagery also should be duplicated by mathematical-numerical models of lakes and shoreline processes. Studies of this kind would be quite fruitful, it would seem, in more definitively establishing those dynamics that disperse pollutants in water bodies. Certainly sequential analyses of lake scenes containing reflectance variations should be done wherever possible because of the clues that these observations offer with regard to circulation dynamics and differentiating depth (non-changing) from turbidity (changing) features.

SOIL MOISTURE, PHREATOPHYTE, RIPARIAN VEGETATION MAPPING, EVAPOTRANSPIRATION, ETC.

Areas Needing Further Research

In the water resources sessions at the ERTS-1 Symposium, no papers were presented which explicitly treated the subjects mentioned for the title of the section. However, several of the papers were related to this subject. In treating the mapping of southern Arizona plant communities, Turner has made observations of phreatophyte communities. Some areas of phreatophyte and/or riparian communities have also been observed in California using ERTS-1 data (Burgy). However, there is still a need, in view of the fact that these plant types, particularly phreatophytes, constitute such a high and sustained transpiration source, to do more work to see if they can be objectively delineated from other plant communities.

A significant number of ERTS-1 investigations indicate that the delineation of soil moisture variations will be part of their objectives. Many ERTS-1 scenes containing irrigated fields illustrate that large and relative differences in soil moisture can be delineated. Areas where rain has fallen recently can be delineated from surrounding dry areas as illustrated in the July 29 playa lakes scene taken near Lubbock, Texas (C. C. Reeves). Still, more research needs to be done and reported before one can say that definitive and useful accomplishments in this area have been made. In the observations of irrigated fields some more work needs to be done showing how accurately one can inventory fields that are under irrigation or very recently irrigated at a given point in time. In addition, ERTS-1 results show that circular irrigated fields can be easily distinguished but the evidence is not so conclusive as to whether crops being irrigated by other methods can be delineated.

In the arid and semi-arid regions, the streams are often quite small but the bordering vegetation does permit the stream channel to be located and followed in ERTS-1 imagery. Some evidence (Burgy, 1973) exists that anomalous vegetation response can be used to locate large and significant leaks associated with reservoirs and/or irrigation canals. It would be interesting to see how many large leaks can be located via this approach in other areas.

OVERALL CONCLUSIONS AND OBSERVATIONS

The ERTS-1 Water Resources Working Group was in overall agreement that the ERTS-1 MSS observations have provided much more useful and applicable hydrological information than was generally anticipated prior to launch. It also appears that these observations are more useful in applied hydrology and water resources than in scientific hydrology. Certainly in the area of applied hydrology (for example, flood-inundated area mapping, empirical snow cover versus expected runoff relationships and so on) there is much more to do. It is felt that finding new and more rapid means of processing large amounts of data and classifying or extracting thematic observations offers very significant challenges. New results appear to be ahead in digital processing techniques applied to hydrology.

A very significant task still confronts the hydrologic remote sensing community in doing studies and pilot application projects that will involve and educate new "users" as to the benefits and applicability of these data. The results achieved after less than one year of the ERTS-1 satellite lifetime suggest that there are a great many more applications ahead and many more water resources management organizations that need to become aware of these data. In addition, the success of ERTS-1 suggests that improved sensors operating at high spatial resolutions and in other spectral intervals such as the thermal infrared and the microwave would also offer exciting new observations. Studies defining the optimal spatial, temporal, and spectral frequencies need to be encouraged so as to make spaceborne systems as useful as possible in solving the problems confronting the "man on the street", particularly in the area of water resources management.

It should be explicitly said that the success and achievements presented and reported to date could only have resulted because of the existence of and the participation by many investigators in an extensive data analysis program Certainly, the investigators who reported at the ERTS-1 Symposium are to be commended for being industrious, responsive, and alert to opportunities for analysis. It is certainly hoped that a vigorous program of data analysis can be continued because the results reported and to be expected in the hydrology and water resources area alone have provided and will provide very ample benefits and cost-effective applications.

APPENDIX 1

PARTICIPANTS IN ERTS-1 WATER RESOURCES WORKING GROUP

U. R. Barnett
Code SA
Kennedy Space Center, Florida

Bruce J. Blanchard
USDA-ARS
Box 400
Chichasha, Oklahoma 73018

Paul Bock
Civil Engineering Dept.
University of Connecticut
Storrs, Connecticut

Robert H. Burgy
Dept. of Water Science and Engineering
University of California
Davis, California 95616

Morris Deutsch
USGS/EROS
Washington, D. C. 20244

Herman G. Hamby
Environmental Applications Office
NASA/MSFC
Huntsville, Alabama 35812

Jean-Paul Malingreau
Dept. of Water Science and Engineering
University of California
Davis, California 95616

A. Rango, Co-Chairman
Code 650.3
Goddard Space Flight Center
Greenbelt, Maryland 20771

C. A. Reeves
Code C09
Johnson Space Center
Houston, Texas 77058

V. V. Salomonson, Chairman
Code 650.3
Goddard Space Flight Center
Greenbelt, Maryland 20771

J. W. Tremor
Earth Science Applications Office
Ames Research Center
Moffett Field, California

APPENDIX 2

PAPERS PRESENTED IN THE WATER RESOURCES SESSIONS AND SOME SELECTED PAPERS PRESENTED IN OTHER SESSIONS THAT CONTAINED PERTINENT RESULTS

AUTHOR(S)	TITLE
Anderson, R. R., V. Carter, and J. McGinness (E7)	Atlantic Coastal Wetlands Mapping (Maryland, Georgia) Using ERTS-1 Imagery
Barnes, J. C. (W18)	Use of ERTS Data for Mapping Snow Cover in the Western United States
Baumgardner, M. F., S. J. Kristof, and J. A. Henderson (A26)	Identification and Mapping of Soils, Vegetation, and Water Resources by Computer Analysis of ERTS MSS Data
Benson, C. S. (W19A)	Snow-Cover Surveys in Alaska from ERTS-1 Data
Burgy, R. H.	The Use of ERTS-1 Data to Aid in Solving Water Resources Management Problems in the State of California
Coker, A. E., A. Higer, and C. R. Goodwin (W20)	Detection of Turbidity Dynamics in Tampa Bay, Florida, Using Multispectral Imagery from ERTS-1
Espejo, R., J. Torrent, and C. Roquero (W2)	Detection of Major River Bed Changes in the River Ebro (northeastern Spain)
Falconer, A., S. H. Collins, W. T. Dickison, R. Protz, R. P. Bukata, K. P. B. Thomson, G. P. Harris, and P. J. Howarth (W14)	Studies in the Lake Ontario Basin Using ERTS-1 and High Altitude Data.

Flores, L. M., C. A. Reeves, S. B. Hexton, and J. F. Paris (W10A)	Unsupervised Classification and Areal Measurement of Land and Water Coastal Features on the Texas Coast
Gilmer, D. S., and A. T. Klett (W12)	Preliminary Evaluation of ERTS-1 for Determining Numbers and Distribution of Prairie Ponds and Lakes
Gold, D. P., S. S. Alexander, and R. R. Parizek (G2)	Analysis and Application of ERTS-1 Data for Regional Geologic Mapping
Hallberg, G. R., B. E. Hoyer, and A. Rango (W5)	Application of ERTS-1 Imagery to Flood Inundation Mapping
Higer, A. L., E. A. Cordes, and A. E. Coker (W10)	Modeling Subtropical Water Level Dynamics Distribution
Hollyday, E. F. (W4)	Preliminary Test of ERTS-1 Imagery for Improving Definition of Natural Streamflow
Klemas, V., and D. Bartlett (E8)	Identification of Coastal Vegetation Species in ERTS-1 Imagery
Lyons, W. A., and S. R. Pease (W17)	ERTS-1 Views the Great Lakes Area
Mairs, R. L., F. J. Wobber, and D. Garofalo (E9)	Application of ERTS-1 Data to the Protection and Management of New Jersey's Coastal Environment
Meier, M. F. (W19)	Evaluate ERTS Imagery for Mapping and Detection of Changes of Snowcover on Land and on Glaciers
Morrison, R. B. (W6)	Assessment of Flood Damage in Arizona by Means of ERTS-1 Imagery
Paulson, R. (W9)	Preliminary Analysis of ERTS Relayed Water Resources Data in the Delaware River Basin
Pluhowski, E. J. (W16)	Remote Sensing of Turbidity Plumes in Lake Ontario
Schumann, H. H. (W8)	Monitoring of Streamflow in the Verde River by ERTS-1 Data Collection System (DCS)

Stoertz, G. E., and W. D. Carter (W1) — Hydrology of Closed Basins and Deserts of South America, ERTS-1 Interpretations

Strong, A. E. (W21) — ERTS-1 Observes Algae Blooms in Lake Erie and Utah Lake

Turner, R. M. (W7) — Use of the SRI Satellite Image Analysis Console for Mapping Southern Arizona Plant Communities from ERTS-1 Imagery

Van Liere, W. J. (W3) — Applications of Multi-Spectral Photography to Water Resources Development Planning in the Lower Mekong Basin (Khmer Republic, Laos, Thailand, and Viet Nam)

Van Tries, B. J. (W11) — An Evaluation of Space Acquired Data as a Tool for Management of Wildlife Habitat in the State of Alaska

Wagner, T. W. and F. Polcyn (W15) — Progress of an ERTS-1 Program for Lake Ontario and its Basin

MARINE RESOURCES AND OCEAN SURVEYS

James R. Greaves
NASA, Goddard Space Flight Center
Greenbelt, Maryland

INTRODUCTION

The purpose of this report is to provide a synopsis of the significant results achieved within the Marine Resources and Ocean Surveys discipline of the overall ERTS program. The prime sources of information for this report were the papers presented at the Symposium on Significant Results Obtained from ERTS-1. At the close of that Symposium a seven-man Working Group was convened to review the papers which had been presented, to provide an evaluation of the work done to date, and to make recommendations for the future direction of the program. Each of the members contributed material relating to specific subdisciplines as well as to the overall program. This report represents an amalgamation of those contributions by the panel chairman. A listing of the Working Group members is included as Appendix 1. Appendix 2 provides a list of the Marine Resources and Ocean Surveys Sessions papers by title and author.

This report is organized by subdisciplines. Within each subdiscipline, the potential of the ERTS system is reviewed, the progress to date is summarized, and particular problem areas are discussed. Finally, this report presents an overview of the status of the Marine Resources and Ocean Surveys discipline within the ERTS program and makes recommendations for the further direction of that program.

SUBDISCIPLINE SUMMARIES

Coastal Processes

Slightly more than half of the papers presented were concerned with coastal processes such as suspended sediment transport, nearshore circulation patterns, beach dynamics, and river effluents. The total number of ERTS studies dealing with coastal processes within the overall marine resources discipline is proportionately the same. The great interest in this particular subdiscipline can be at least partially explained by its relatively immediate impact on man's activities. Potential applications include:

- Environmental Analysis–The entry of sediment into suspension may constitute erosional damage, and its deposition may be damaging to channels, harbors, and biologically productive wetlands or seafloors

- Monitoring pollution—Suspended sediment may be considered a pollutant because of its detrimental effects on certain organisms and because it frequently contains adsorbed metallic and organic pollutants
- Planning nearshore measurement programs using point sensors of oceanographic variables—The use of ERTS imagery to establish circulation patterns can aid in the design of such programs and can assist in interpreting the measurements obtained
- Determining changes in coastal areas, such as beaches and barrier islands, after storms and hurricanes
- Obtaining information for planning and construction in remote areas of the world

Summary of Significant Results

Suspended sediment proved to be the most clearly visible feature in the nearshore water, allowing limited correlation between the actual sediment load and photographic film density. Although Band 4 penetrates more deeply into the water and detects weaker suspended sediment concentrations than Band 5, investigators along the east coast of the U.S. have found considerable haze in Band 4, which tends to mask the images. This has led to a preference for Band 5 for most nearshore sediment-related applications (see Table 1).

Table 1
The Coastal Features Most Clearly Discerned
in the Indicated Spectral Bands.

Coastal Feature	ERTS-1 Bands			
	4	5	6	7
Suspended Sediment	F	G	F	
Circulation (currents)	F	G		
Boundaries and Fronts	F	G		
Water Masses	G	G		
Bathymetry and Submarine Shoals	G	F		
Coastal Changes and Littoral Movement		F	G	G
Land/Water Delineation			F	G

G = Good Visibility
F = Fair Visibility

Because of the low brightness range available in water areas of the ERTS imagery, computer-compatible tapes have been found to be superior in bringing out the sedimentation patterns. Sediment acts as a tracer, allowing nearshore circulation (current) patterns, direction of net water transport, and boundaries between different water masses to be discerned.

The ERTS-1 imagery, particularly Bands 6 and 7, along with imagery from supporting aircraft underflights, is being used to detect seasonal as well as storm-induced changes in beaches and shorelines. It is anticipated that the linear character of many beaches will allow significant changes to be detected even with the limited resolution of ERTS imagery.

Problem Areas

The greatest deterrent to the interpretation of nearshore sediment or water-mass features in the ERTS imagery has been the lack of adequate gray-scale gain within the relatively dark ocean areas. To some extent, this problem can be circumvented through the use of computer-compatible types.

Since beach widths are characteristically on the order of a few to several tens of meters, studies of beach and shoreline dynamics may require imagery of higher resolution than is available with ERTS. Extensive ground and aircraft support will be required before the accuracy of quantitative measurements from satellite data can be evaluated.

In order to develop time histories of sediment-plume movements, an increased coverage frequency would be desirable, possibly every three or four days.

Although the problem of atmospheric effects was mentioned by a number of investigators, there was no discussion of possible techniques for separating out these effects. The usefulness of an additional blue band for greater water penetration may depend upon our ability to develop such techniques.

Bathymetry

There are about 130,000 kilometers of world coastline. Within these relatively shallow coastal waters, the greatest density of shipping occurs. Yet the status of available hydrographic charts around the world is generally inadequate. Phrases such as "position appropriate" and "existence doubtful" are frequently seen on existing charts. The resources which would be required to accurately update the existing charts by conventional means would be prohibitive. Moreover, the dynamic nature of many submarine features would quickly invalidate the observed profiles. The synoptic and repetitive coverage provided by satellite-borne sensors may provide us for the first time with accurate tools to generate up-to-date hydrographic charts of the world's coastal waters and shallow seas.

Maximum transmission of light in clear seawater is in the 0.47- to 0.48-μm blue-green spectral region. In coastal waters, suspensions of sediment, biological matter, and pollutants alter light transmission and shift the water window toward the longer-wavelength green and yellow spectral regions. Although ERTS-1 does not have a blue spectral band equivalent to that sensed by the Gemini and Apollo color film, it has been shown that MSS-4 and -5 images are useful in recording bottom topography.

Summary of Significant Results

In clear water, the use of contrast enhancement as well as optical and digital density slicing can be used to infer relative depths in 2-, 5-, and 10-meter steps from the surface down to about 20 meters (Ross).

An analytic technique to calculate absolute depth values, based upon the ratios of adjacent MSS channels where some knowledge of bottom reflectivity is available, was presented by Polcyn. Although preliminary results are encouraging, it has not yet been demonstrated that ERTS data can be used to calculate absolute water depths.

It is clear that through careful analysis the current ERTS system can be used to make relative depth measurements. Even without absolute depth information, ERTS imagery could aid the hydrographer by greatly reducing the number and length of transects required to sound a large area, and by identifying areas requiring close investigation. Bathymetric surveys of specific areas could be scheduled only as required.

Problem Areas

Relating density information in ERTS images to water depth must be done with caution because there are many factors other than depth which affect the observed brightness. These include:

- Bottom surface characteristics–A homogeneous, highly reflective bottom surface will be quite different in appearance than a nonhomogeneous, nonreflective surface at the same depth
- Water turbidity–Light-colored sediments in the water can give false indications of shallow water
- Water surface reflectance–Large areas of wind-generated whitecaps below the sensor resolution limits could be interpreted as lighter, more shallow areas
- Atmospheric effects–Variations in haze or water vapor in the atmosphere could cause anomalous depth determinations

The usefulness of the current ERTS system for making depth measurements is limited by both the lack of a blue-band channel and the lack of a sufficient density range within the water areas. Work in this area generally suffered from a lack of surface truth, and investigators instead cited good correlations with available hydrographic maps. Some surface-truth work will be required before the validity of the optical or digital techniques can be properly assessed.

Sea Ice

In recent years, the economic development of Arctic Alaska has become of particular national interest. Regardless of the eventual decision regarding oil transport, economic development will require an increased understanding of the region's natural character and the processes operating to maintain or change that character. Ice is perhaps the most important agent affecting these processes. It is a source of coastal water type, it disrupts and redistributes bottom sediments, and it influences shelf circulation patterns. In addition to its obvious impact on shipping activities, sea ice plays a critical role in the heat balance of the Arctic and may be an important factor in the climate of the northern hemisphere.

Despite the importance of adequate ice information, the harsh and remote polar environment has required the use of slow and costly methods for data acquisition. It now appears that satellite-borne remote sensors will play an increasingly vital role in bridging this observational barrier. The application of ERTS data to this problem area was summarized in two papers presented at the ERTS Symposium. One dealt largely with system evaluation and technique development, while the other was more applications-oriented and dealt specifically with the coastal marine environment of the Beaufort Sea, Alaska.

Summary of Significant Results

J. C. Barnes presented an evaluation of the potential of ERTS data for detecting and mapping sea ice. His conclusions are that sea ice is detectable in all of the ERTS MSS spectral bands and can be distinguished from clouds through a number of interpretive keys. Overall, MSS Bands 4 and 5 appear to be better for mapping ice boundaries, whereas MSS Band 7 provides greater detail in the ice features. Considerable information on ice type, size, and concentration can be derived from the ERTS data. The day-to-day sidelap at Arctic latitudes is such that ice features can be tracked for several days, providing new insight to the circulation patterns of the polar seas. MSS Bands 4 and 7 can be combined to infer the presence of melt water on the ice and to map snow lines on glaciers.

In conjunction with extensive field data, P. W. Barnes has extracted the following information from the ERTS images:

- Surface distribution of suspended matter, temperature, and salinity along the coast—A combination of field measurements and ERTS imagery can be used to readily distinguish the three surface-water types of river runoff, ice-melt, and oceanic waters. Each water-mass type has its own temperature, turbidity, and salinity signatures.

- Determination of coastal currents and ice movement from grounded ice and image sidelap—Ice movement and distribution will play an important part in any shipping and economic development along polar coastlines. Although wind and ice movements are generally well correlated, the ERTS images show departures from this relationship, probably due to the added influence of currents and coastline shape.

- Correlation of grounded ice with submarine ridges—Masses of grounded ice have been observed along submarine ridges (for example, see ERTS MSS image E-1020-21281-5). These observations have a number of practical implications.

The safety of offshore structures and pipelines depends upon the depth and distribution of ice grounding. Moreover, shipping will be guided by the presence or absence of barriers to onshore movement of ice.

Problem Areas

Careful photographic processing of the original 70mm negatives has been found to be necessary, since exposures selected to retain detail in land areas can result in the loss of significant ice features. Also, for the detection of iceberg navigational hazards, a greater spatial resolution coupled with a more repetitive orbit would be desirable.

Oceanic Circulation and Dynamics

From the previous sections it is apparent that in the nearshore environment the ERTS-1 data may be interpreted with a generally high degree of confidence. Over the open ocean, analysis becomes more difficult. Color variations become more subtle and the color itself shifts further toward the blue portion of the spectrum (that is, less than 0.5 μm, the lower limit of the shortest wavelength channel). The evidence of sea-air interactions becomes more pronounced and less understood.

Summary of Significant Results

The paper by Hanson dealt with oceanic features in the lee of the Windward and Leeward Islands. Reduced radiances were observed in all four MSS channels on the leeward side of the Lesser Antilles during a mid-October pass. A ship survey a month later showed no anomalous conditions and, indeed, an ERTS pass made a few days after the ship measurements no longer showed the darker areas. The patterns observed in the October pass may have been related to sea-state changes or to increased phytoplankton, or may have been totally atmospheric in nature. Based upon the available information, no firm conclusions could be reached.

The intent of the study by Maul was to generate a time series of observations across the boundary of the Loop Current in the Gulf of Mexico, using ocean color as the discriminator. Because of a lower chlorophyll—a concentration and a lower volume scattering coefficient—one would expect the waters of the Loop Current to be less reflectant in the MSS-4 Green Band than the surrounding Gulf water would be. The exact opposite has been found in the ERTS data. The discrepancy is attributed to higher sea-state conditions within the Loop Current, with the attendant increase in foam and whitecaps. The implication of this is that in the determination of ocean color from remote sensors, the matter of sea state must be considered as a dominant variable. On the position side, the possibility of quantitatively estimating sea state is raised.

Problem Areas

Nowhere is the requirement for adequate surface-truth information more evident than in the open ocean. One of the anomalous observations noted above is transitory in nature and still has no adequate explanation. The other has been attributed to changes in sea state, although this has yet to be proven conclusively. Surface truth in the open ocean should consist not only of measurements in the water itself, but also in the atmosphere above the water.

Living Marine Resources

Three papers were presented which fell into the living marine resources subdiscipline. Szekielda dealt with assessment of the biomass in the upwelling area along the northwest coast of Africa, where there is no river discharge; changes in water color are thus primarily produced by plankton organisms. The papers by Kemmerer and Maughan dealt with the correlation of environmental and biological parameters, the assessment of the biomass, and the utilization of these correlations and assessments in the management of the menhaden fishery resource in the Mississippi Sound.

Summary of Significant Results

Correlations between variation in radiance data from the ERTS MSS and surface-acquired chlorophyll and turbidity data were demonstrated, but there is some doubt as to whether the width of the MSS bands will allow a quantitative separation of these effects. Consistent quantitative relationships cannot be developed until atmospheric correction techniques are developed for the visible and near-infrared portions of the spectrum. Further work is required in the understanding of sea state and incoming (sky) radiance effects on the general measurement of water color.

Simple models have been developed showing significant correlation between menhaden fish stock availability and salinity, water color, and depth. Qualitative correlations have been established between high-radiance levels in MSS Band 5 and location of menhaden fish schools as determined by surface observations at the time of the satellite overpass.

Problem Areas

Before operational application of ERTS data can be made to living marine resources, better understanding of the relationships between environmental parameters and biological parameters must be developed. It is only now with the advent of remotely acquired synoptic data on environmental parameters that these relationships can be developed. Once the biological relationships are understood, they may be utilized in management of the resource.

Specific modifications to ERTS-type spacecraft should come in the form of the addition of a blue channel to the multispectral scanner system and the return beam vidicon. At the present time, the 18-day repeat time is acceptable for experimental purposes, but in an operational mode a three- to four-day repeat cycle is required.

OVERVIEW

This final section of the Summary Report presents an overview of status of the Marine Resources and Ocean Survey disciplines within the ERTS Program and makes recommendations for the future direction of that program. The two general topics to be considered are: (1) the adequacy of the ERTS-1 sensor complement and (2) the adequacy of the investigations.

The Sensor Complement

It has often been noted that ERTS-1 was not designed for oceanographic applications. It is certainly true that the emphasis on dry-land applications has tended to limit both the quantity and quality of significant results within the oceanography discipline. Table 2 summarizes, by subdiscipline, the modifications to the present ERTS-1 system most often sought by the Symposium speakers.

Table 2
Desired ERTS-1 Modification by Subdiscipline.

Subdiscipline	Modification: Increased Sensitivity	Addition of Blue Band	Increased Spatial Resolution	Increased Observation Frequency
Coastal	++	++	+	+
Bathymetry	++	++	+	-
Sea Ice	+	-	+	+
Oceanic Circulation	++	+	-	-
Living Marine Resources	++	+	+	++

Key: ++ = Most Desired, + = Desired, - = Little Impact

The lack of sensitivity at the lower end of the visible range in the ERTS imagery clearly emerges as the most serious deficiency. It is recommended that consideration be given to the following possible solutions:

- Establish a plan which would define orbits (or fractions thereof) dedicated to operating in a high-gain mode
- On a trial basis, possibly in cooperation with a few selected investigators, have Ground Data Handling Facility (GDHF) put out a special product with prime emphasis on water areas, thus providing a uniform product rather than having each investigator process his own imagery

The remaining three modifications would require basic design changes to the ERTS observing system. Of these, the most desired feature is the addition of a blue band peaking at about 0.47 μm, which is particularly needed in the coastal and bathymetric areas.

The Investigations

Better coordination between surface-truth teams, aircraft, and satellite is required for close correlation of the data. In some cases "conclusions" were reached without a single piece of corroborating surface data. It should be recognized by NASA that in the oceanographic discipline, an adequate surface-truth program is a costly undertaking. Investigators working in the same area should be encouraged to pool their surface-truth efforts to minimize cost and maximize the reliability of their results. An excellent example is provided by the menhaden fisheries studies, where cooperation between participating government agencies and industry has established effective communication links for user problem areas and development of cost-effective procedures.

There was little or no mention of atmospheric effects in the Symposium papers. The effects of the atmosphere will have to be clearly understood before final conclusions can be reached regarding the correct interpretation of the patterns observed and their translation into quantitative oceanographic parameters. The spectral characteristics of the desired blue band will have to be defined with the potential effect of the atmosphere in mind.

In the case of Marine Resources, ERTS provides the data for the development of satellite techniques to measure water color, infer circulation and upwelling, and possibly infer temperature and salinity regions by correlation with other surface-acquired data. The measurement of water color may further be related to chlorophyll and turbidity. These measurements may then be combined, interpreted, and formatted in terms of sets of information for scientific or operational application. Program guidance should be given by NASA to the investigators to reduce some of the redundancy in technique development and to exploit the applications capabilities.

Most papers dealt exclusively with the development of measurement techniques. Few discussed applications techniques or cost benefits. Those applications referred to in the subdiscipline discussions above were generally supplied by the working group members rather than by the Symposium speakers. It is recommended that a formal mechanism be established for documentation by the investigators of potential applications, including cost effectiveness. A separate required report devoted to that subject would be one possibility.

Concluding Remarks

Oceanography was established as a major geophysical science in 1872 with the sailing of the H.M.S. *Challenger* on a 1000-day cruise. The sampling plan of fixed stations widely separated in time and space has been altered little in the ensuing 100 years. A modern research vessel would still require nearly 300 days to duplicate the *Challenger's* expedition, at an operating cost approaching one million dollars. What is required is a network of information much denser in both time and space, particularly for the superficial sunlit layers of the ocean which are the sites of all the primary biological productivity and through which rapid energy exchanges occur. Despite its shortcomings for oceanographic applications, ERTS-1 is clearly demonstrating the potential for rapid and continuous oceanic surveys. The synoptic view afforded by such a satellite platform represents a newly acquired tool of the oceanographic community. It should be anticipated that there will be a period of learning and familiarization on the part of the oceanographic community before the potential of this new tool can be fully realized.

APPENDIX 1

PARTICIPANTS IN ERTS-1 MARINE RESOURCES AND OCEAN SURVEYS WORKING GROUP

Howard J. Curfman, Jr.
NASA, Langley Research Center
Hampton, Virginia 23365

Gifford C. Ewing
Woods Hole Oceanographic Institute
Woods Hole, Massachusetts 02543

James R. Greaves, Chairman
NASA, Goddard Space Flight Center
Greenbelt, Maryland 20771

Vytautas Klemas
University of Delaware
Newark, Delaware 19711

Paul M. Maughan
Earth Satellite Corporation
Washington, D. C. 20006

John W. Sherman, III
NOAA/NESS Oceanography Group
Hillcrest Heights, Maryland 20031

E. L. Tilton
NASA/Mississippi Test Facility
Bay St. Louis, Mississippi 38520

APPENDIX 2

PAPERS PRESENTED IN THE MARINE RESOURCES AND OCEAN SURVEYS SESSIONS

AUTHOR(S)	TITLE
Anderson, Duwayne M., Lawrence W. Gatto, and Harlan L. McKim (M9)	Sediment Distribution and Coastal Processes in Cook Inlet, Alaska
Barnes, James C. (M14)	Use of ERTS Data for Mapping Arctic Sea Ice
Barnes, Peter W., and Erk Reimnitz (M7)	New Insights into the Coastal Marine Environment of the Beaufort Sea From Field Data and ERTS-1 Imagery
Bowker, D. E., P. Fleischer, T. A. Gosink, W. J. Hanna, and J. C. Ludwick (M4)	Correlation of ERTS Multispectral Imagery with Suspended Matter and Chlorophyll in Lower Chesapeake Bay
Carlson, Paul R., Richard J. Janda, and T. John Conomos (M6)	Observations of Suspended Particle Patterns in Nearshore Northeastern Pacific Ocean Waters by ERTS-1 Imagery
Hanson, Kirby J. (M12)	Oceanographic Features in the Lee of the Windward and Leeward Islands: ERTS and Ship Data
Hunter, Ralph E. (M10)	Distribution and Movement of Suspended Sediment in the Gulf of Mexico off the Texas Coast
Kerhin, Randall T. (M2)	Recognition of Beach and Nearshore Depositional Features of Chesapeake Bay
Klemas, V., R. Srna, and W. Treasure (M3)	Applicability of ERTS-1 Imagery to the Study of Suspended Sediment and Aquatic Fronts

Lepley, L. K., Gustavo Calderon, and J. R. Hendrickson (M11)	Oceanographic Mapping of Structure and Dynamics of the Northern Gulf of California by the Use of Spectral Modeling and ERTS-1
Maughan, Paul M. (M17)	Application of ERTS-1 Imagery to the Harvest Model of the U. S. Menhaden Fishery
Maul, George A. (M13)	Remote Sensing of Ocean Currents Using ERTS Imagery
Polcyn, Fabian C. (M20)	Calculations of Water Depth from ERTS MSS Data
Ross, D. S. (M19)	Water Depth Estimation with ERTS-1 Imagery
Ruggles, Frederick H., Jr. (M5)	Plume Development in Long Island Sound Observed by Remote Sensing
Slaughter, Turbit H. (M1)	Seasonal Changes of Littoral Transport and Beach Width and Resulting Effect on Protective Structures
Szekielda, Karl-Heinz, Dr. and R. J. Curran (M15)	Biomass in the Upwelling Areas Along the Northwest Coast of Africa as Viewed with ERTS-1
Williams, Richard S., Jr. (M18)	Plymouth and Duxbury Bays, Massachusetts: Subaerial and Submarine Features Depicted on MSS Imagery as Compared with Aerial Photography and Conventional Maps at 1:1,000,000; 1:250,000; and 1:125,000 Scales
Wright, F. F., G. D. Sharma, and D. C. Burbank (M8)	ERTS-1 Observations of Sea Surface Circulation and Sediment Transport, Cook Inlet, Alaska

Supplemental Program

Kemmerer, Andrew J., and Joseph A. Benigro (M15A)	Relationships Between Remotely Sensed Fisheries Distribution Information and Selected Oceanographic Parameters in the Mississippi Sound
Magoon, Orville T., Dennis W. Berg, and Robert J. Hollesmeier (M10A)	Application of NASA ERTS-1 Satellite Imagery in Coastal Studies

INTERPRETATION TECHNIQUES DEVELOPMENT

William L. Alford
NASA, Goddard Space Flight Center
Greenbelt, Maryland

INTRODUCTION

The Interpretation Techniques Development Working Group, which met on March 9, 1973 considered the results presented in 21 papers. The members of the Working Group are listed in Appendix 1, and the papers are listed in Appendix 2.

This summary is based on the following definition of *interpretation techniques*. Those processes, algorithms, and procedures which allow the extraction from acquired data of that information required to detect, evaluate, monitor, or manage a resource activity. It is clear from the presentations of this ERTS Symposium that powerful techniques now exist for the extraction and display of this information. These techniques have been demonstrated repeatedly in every one of the disciplinary sessions of this Symposium. It is also apparent from these same disciplinary sessions that additional techniques development is warranted in order to increase the accuracy of the materials classified, to allow the detection of more subtle environmental effects, and to provide more cost-effective methods.

The number and variety of interpretation techniques are almost unlimited, constrained only by the number and variety of disciplinary requirements and the facilities of the user. However, a generic class of techniques is applicable to ERTS analysis—namely, image processing techniques. Conventional techniques such as photointerpretation have reached a level of near stability insofar as new development is concerned. Current emphasis is being placed on machine-aided photoanalysis, image correction and enhancement, and automated data processing. For this summary, interpretation techniques have been subdivided into three categories: Classification, Radiometric Correction, and Geometric Correction and Area Mensuration.

GENERAL SUMMARY OF SIGNIFICANT RESULTS

Analysis of data acquired temporally is possible through geometric correction, correlation, and registration techniques. Valuable information can be obtained from within a resolution element—a fact which could have significance not only as far as use of current data, but also for its effect on future sensor design. The powerful techniques in image enhancement developed for the lunar and planetary programs are also valuable for the Earth Resources Survey programs. There is evidence that both optical and digital methods of spatial information extraction can provide valuable sources of data information from the ERTS system.

The techniques available, even for a limited number of bands (4) and limited resolution (80-meters IFOV) can be effectively used to extract much of the information required by resource managers. A variety of new techniques is required based upon the budgets and requirements of the earth resources investigations. Many users do not have access to the more powerful techniques enjoyed by the larger agencies. There is, and will be for some time to come, a large involvement required by the analyst as well as resource manager in the application of the techniques.

CLASSIFICATION

Summary

This area is maturing normally in that major breakthroughs are diminishing, and a set of trends or specializations can be identified. In particular, eight major trends have been defined:

- extraction of spatial image content
- exploitation of the temporal dimension
- man-machine interaction
- operational integrated systems
- concern for user education
- cost consciousness
- photo-optical techniques finding new support
- known mathematical techniques refinement

Most papers presented at the Symposium exemplified more than one of these trends, a condition the reviewers consider healthy.

Particular highlights of the papers include subpixel classification (Malila and Nalepka; Cousin, Paris, Potter, and Anderson), a systematic approach to optimal gray scale manipulation (Algazi), matrixing spatial and spectral classification results for improved accuracy (Shanmugam and Haralick), manual partitioning of data for better computer utilization (Nichols), the increase in the number of classes addressable by texture over those previously reported (Gramenopoulos), and the efforts toward time-lapse studies evidenced in several papers, even though multiple coverage of given ground locations has only lately become available.

It is to be noted that, in general, technique development is a time-consuming undertaking, and we are likely to see the continuing emergence of more efficient techniques from research efforts now going on, but the trends observed in these reports are expected to remain stable.

Assessment

The demonstrated ability to identify crops on a field-by-field basis, to find areas of good fishing, and to classify remote regions points to the worth of present data-extraction techniques. The Interpretation Techniques Development sessions further brought out the fact that a great many tried and true techniques work well with ERTS data.

The overriding and ever-present problems are those of finding alternatives to the expensive and cumbersome methods of extracting information from ERTS images presently used. These alternatives generally involve by-passing the general-purpose digital computer by using special-purpose digital machines or by using photo-optical techniques. In addition, many of the papers presented explored how human interaction in the extraction loop can lower costs and lead to less cumbersome extraction systems.

Future Direction

The NASA Data Processing Facility (NDPF) should produce products, both film and tape, registered to UTM grid. Such products will allow both film and tape users to do temporal classification and change detection faster at much lower cost. UTM Grid registration also permits low-cost production of map and grid overlays and expedites updating.

Image information-extraction systems should be developed that are fast, low cost, and easy to operate under user control. The systems should have spectral, spatial, and temporal analysis capability as well as effective interactive features to allow image interpretation by the user/operator. Systems could consist of regional computer centers with programmable special processors to reduce cost and user-service reaction time. Such systems should also support multi-interactive terminals for user/operator control.

In order to expedite the extraction of user information from image data, a systematic procedure is needed that will allow a user to select those processing techniques—from the large number of techniques available—which are most suitable for his application. The procedure will allow the user to identify the techniques needed, the processing cost and time, the most appropriate input and output formats, where the techniques are available, supporting ground-truth requirements, as well as have other advantages.

More research is required on the classification problem in the areas of automated clustering, spectral feature selection, decision boundary shapes, and comparisons between short-cut methods such as those used at JSC and JPL and the more precise methods such as that used at LARS. Continued improvement in estimating intrapixel mixtures should be used to extend the technique to multiple component mixtures with unknown constituents.

RADIOMETRIC CORRECTION

Summary

Papers dealing with data corrections were generally concerned with two topics:

- Removal of instrumental effects (RBV shading and MSS striping, for example)
- Calculation of the amount of atmospheric transmission and path radiance and computations of atmospheric turbidity

Instrumental Effects Removal

For RBV shading effects, a film-mask technique was described that offered improved correction of RBV shading functions over the correction provided by the NDPF (Ross). This technique should be of interest to those who require uniform-response RBV images. For MSS banding effects, techniques were described that identify and correct the condition (Cousin, Paris, Potter, and Anderson; Bernstein; Billingsley and Goetz). The techniques may be useful to photointerpreters in avoiding misclassification in pattern-recognition systems.

Atmospheric Effects

Several papers discussed model computation of atmospheric effects (Fraser; Rogers and Peacock; Cousin, Paris, Potter, and Anderson; Malila and Nalepka; Griggs). Some model calculations show 5 percent variations in path radiance across the scene under typical atmospheric conditions in the Midwest. The model calculations presented were in general agreement with supporting measurements (that is, with aircraft multispectral data). From papers presented at this and other sessions, the severity of atmospheric effects on pattern-recognition processors cannot be entirely evaluated.

Also, a paper was presented on attempts to measure atmospheric turbidity by assessment of contrast reduction. Preliminary results have been reasonable. Another paper described an instrument for making radiance measurements (Rogers and Peacock). These measurements may be useful for correction and for assessing the nature of atmospheric effects.

Assessment

Instrumental Effects Removal

Some problems of instrumental effects removal were discussed. A question was raised about the polarization sensitivity of the system and its impact on radiometric calibration. Similarly, questions of the accuracy and nonlinearity of radiometric calibration and changes in system performance were not fully addressed. In some of these areas, NASA personnel have the most recent information, which should be shared.

Atmospheric Effects

The severity of the atmospheric effects on the ERTS system must be considered in the light of the type of processing done, the difficulty of the problem addressed, and the sensor system capabilities such as noise equivalent radiance and quantization of data. In sessions other than the Interpretion Techniques sessions, papers were presented showing good pattern-recognition results either over small sections of an ERTS frame (for example, three counties in north-central Illinois) or in extremely clear atmospheric conditions (as in the Yellowstone National Park frame). Because reliable pattern recognition is feasible for some ERTS-1 scenes, the conjecture that changes in atmospheric properties within ERTS frames degrade pattern-recognition performance cannot be reliably evaluated at this time. There is a need for further verification of accuracy of the models used for calculation of atmospheric effects. Some investigators of atmospheric effects and turbidity are just beginning to work with digital ERTS data and supporting aircraft data. Consequently, more fruitful results should be forthcoming from these investigators.

Future Direction

The need for atmospheric corrections has to be established by comparing data-reduction algorithms with and without atmospheric corrections. The atmospheric effect on the data depends on the type of remote sensing problem. In some cases, the effect is weak, as in the detection of fault lines; in other cases the effect is strong, as when measuring the chlorophyll content of water. One approach to analyzing atmospheric effects is to make parametric studies with atmospheric models and with models of surface reflection that are of interest to the ERTS investigations.

As classifications become more accurate, as the classified areas increase in size, and as the periods involving a classification increase, atmospheric effects will become more apparent. In order to assess their significance, the spatial and temporal correlations of the radiant energy reaching a satellite will have to be established. The available ERTS, aircraft, and ground-truth data may possibly be used for this purpose.

Preprocessing techniques of the ERTS measurements to reduce atmospheric effects should continue to be developed.

GEOMETRIC CORRECTION AND AREA MENSURATION

Summary

Classification/Area Mensuration

Area mensuration may be considerably in error if only whole pixels are considered. Significantly more accuracy can be obtained by estimating the relative proportions of materials within pixels that span the border between areas of differing materials (Malila and Nalepka; Cousin, Paris, Potter, and Anderson). Geometric rectification in which an output pixel is calculated by proportional interpolation from the input picture can produce pixels containing mixtures at the borders and can thus further degrade the classification process (Rifman).

Geometric Corrections

A geometric correction is normally accomplished by erecting a uniform-output picture grid and obtaining the required data from the input picture either by choice of the nearest neighbor or some form of interpolation. Selection of the nearest neighbor produces an output picture containing local distortions that are visible upon close inspection but may not affect overall analysis (Rifman). Interpretation between input pixels will eliminate the local distortion but will produce output pixels containing mixtures of materials. First-order interpolation and an interpolation from a calculated filter function are being investigated (Rifman, Billingsley and Goetz). The data locations of the input picture can be calculated by an affine surface fit to measure the pass-point displacements (Bernstein) or by piecewise linear interpolation between them (Billingsley and Goetz). No theoretical argument was presented for either approach, but visible differences seem to be negligible.

Registration and Cross Correlation

Obtaining pass-point displacements to be used for the geometric correction is usually done by some form of cross correlation between selected points. Two papers show the results of digital registrations that allow corrections to less than one pixel (Bernstein, Billingsley and Goetz). Bernstein has paid particular attention to processing speed and has produced all-digitally processed images with processing times comparable to NDPF electro-optical processing. This approach also recognizes ground control points to produce a scene-corrected image of relatively high map accuracy. A fifth-order surface is used to fit the measured pass-point displacements.

Display of time-sequential photography dynamically aids the analyst in noting and analyzing the changes, but such a display requires fairly good registration between the time-lapse photos (Evans and Serebreny). Changes may also be detected by producing difference pictures from the time-lapse photographs. Since hard copy from this process may be viewed at leisure, registration must be to less than one pixel because distortions greater than this are readily visible (Billingsley and Goetz). One difference picture shows numerous local areas containing horizontal misregistration between areas of good registration; the cause of this is unknown but is suspected to be the NDPF line-length correction process (Billingsley and Goetz).

Positional Accuracy and Residual Distortion

The actual center coordinates of system-corrected images have been compared with the coordinates given in the annotation block. Differences of more than five kilometers have been measured, but improvements in the NDPF indicate that later images may be in the range of one to two kilometers. After translation, rotation, and scaling of the system-corrected images to UTM ground control coordinates, the residual rms distortions are 200 to 450 meters for the MSS and 100 to 150 meters for the RBV. Later MSS images are tending to cluster between 200 to 300 meters, and some further improvement may be possible (McEwen).

Overall Systems

Complete digital image-processing systems are in use at JSC (Cousin, Paris, Potter, and Anderson) and JPL (Billingsley and Goetz). JSC reported on their system design and discussed their technique for preprocessing, classification, correlation with ground control points, and spectral analysis (Cousin, Paris, Potter, and Anderson). The JPL VICAR system, which is available from COSMIC, contains flexible capabilities for (1) geometric corrections and interpicture registration; (2) various enhancements and analyses of the data, including multispectral and texture analysis; and (3) for display of images in black and white and color (Billingsley and Goetz). The digital processing reported by IBM was performed at their image-processing facility in Gaithersburg, Maryland. There is also a digital system at LARS, Purdue University. SRI has developed a system utilizing the application of television editing and animation techniques that displays time-lapse sequences and provides quantitative measurements of areas of varying materials (Evans and Serebreny). The SPARC system at the Environmental Research Institute of Michigan has been used by several investigators for hybrid digital-to-analog processing.

Assessment

All of the techniques reviewed above involve digital processing. In spite of the more readily available photographs and the lower cost and wider availability of photographic processing, the interest in techniques of digital processing is seen as a result of several factors. Digital MSS data are inherently registered between bands within a single frame, thus avoiding registration problems. The incoming radiometry is preserved (in spite of temporary problems with banding), allowing precisely controlled enhancements and analyses. (There are calibration errors in the current MSS; however, these can be removed in future implementations.) Digital processing allows precise geometric corrections to be made for interpicture registration and for correlation to ground control points and can also produce outputs that permit accurate location measurements at the pixel level. Digital processing produces a variety of image outputs that are in common register with the original image. In addition, it can routinely produce numerical and statistical results.

Digital techniques have been demonstrated that can accomplish the various geometric transformations required for picture registration, and so on. Continued development is required, however, to make digital techniques more economical and hence more widely available.

All ERTS investigations and the NDPF are presently relying on ground control points to correctly position the image with reference to map coordinates. Well-defined points have been measured on existing maps to accuracies of 10 to 30 meters over most of the

United States, and this accuracy is adequate for the present image quality. Other parts of the world do not have a sufficient number of selected ground control points and, except for some areas (Europe, for example), may not have adequate maps to select ground control points.

Future Direction

Present geometric corrections are accomplished fairly slowly because of the extensive interpolation required. A fast special-purpose interpolator could be built for the relatively stable geometric parameters of ERTS; it could be used as a computer peripheral to greatly speed processing times. Geometric correction is also slowed appreciably by the repeated access to the input picture; this effect can be minimized by providing extremely large size random-access memories. Elapsed times for digital processing can be significantly reduced if more efficient input/output media (such as the new higher-density computer-compatible tapes) are used.

Several processing modifications can be evaluated experimentally at the NDPF. The present method for equalizing MSS line lengths by adding pixels should be examined as a cause of the localized misregistration that has been experienced. Also, with suitable software, the Canadian two-pass system for scene-corrected images could be evaluated on the NDPF electron-beam recorder.

Although the number of sequential images over a given test site is presently limited, many investigators agree that multiple scenes are of considerable value. On a larger scale, there is the issue of providing a common reference system for all earth resources data regardless of source (ERTS, Skylab, aircraft, ground, post-ERTS). Some study should occur as to the usefulness of casting the ERTS pictures into a standard external XY system such as the UTM. This would have the advantage of providing users with images or image tapes that would need no further geometric manipulation for registration. It would involve a massive digital-processing effort during initial processing but greatly reduced processing and computer memory requirements for all other users. It would allow direct entry and retrieval by many of the land-use and environmental data banks. The question would also have to be resolved as to whether the geometric manipulation should involve nearest-neighbor selection to avoid producing pixel mixtures.

The present system of relying on ground control points requires continued investigation and evaluation. Recognition of control points in the image or digital data relies on cross-correlation techniques that can be improved and simplified. Seasonal effects on the ground control points should be evaluated. The requirements and accuracy for world-wide extension of control should be estimated. In addition, the attitude history of ERTS-1, when properly evaluated, will give information that may reduce the requirement for ground control. For future earth resources spacecraft, precise attitude information should be considered to reduce or eliminate ground control.

The usefulness of providing all digital processing at NDPF or at selected field centers should be evaluated further because it allows the production of a variety of first-generation products at full resolution. The emphasis on digital processing implies a long-range problem of digital storage and transmission of pictures. In this sense it must be considered that the standard magnetic tapes (800 and 1600 bpi) are obsolescent for major users, and that other methods should be sought for low-cost and easy duplication and dissemination. It is felt that digital processing will be necessary for a large part of the ERTS analysis; efforts should be extended to transfer a digital system, such as VICAR, to smaller computers to allow it to be more widely used.

CONCLUDING COMMENT

Both at Goddard and outside facilities, computer processing of ERTS images requires substantial amounts of money. At Goddard alone the installation of the ERTS image-processing facility cost $30 million, and $5 million a year is required to operate the facility. Figures like these are matched by other organizations. As more earth observation satellites are launched, and as the coverage of these satellites increases, interpretation techniques will become the bottleneck. Money will be saved when techniques are improved so that Goddard can do less processing and still put out a useful product. Money will be saved when both software and hardware are improved so that users can extract their data without recourse to expensive computers. When techniques and hardware are even further improved, image processors will be placed aboard earth-observing spacecraft, allowing users to directly interrogate the on-board processor and greatly reduce the requirements of ground computers. In the perfecting of earth resources satellites, the development of the best possible interpretation techniques is essential.

APPENDIX 1

PARTICIPANTS IN THE ERTS-1 INTERPRETATION TECHNIQUES DEVELOPMENT WORKING GROUP

William C. Alford, Chairman
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Fred C Billingsley
Jet Propulsion Laboratories
Pasadena, California 91103

George Chafaris
General Electric Space Division
Beltsville, Maryland 20705

Jim Dragg
NASA/Johnson Space Center
Houston, Texas 77058

Richard Economy
General Electric Space Division
Valley Forge, Pennsylvania 19481

D G Ferneyhough, Jr.
IBM
Gaithersburg, Maryland 20760

Robert S Fraser
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

R. Michael Hord
Earth Satellite Corporation
Washington, D. C. 20006

H. E. Maurer
NASA/Wallops Station
Wallops Island, Virginia 23337

Robert B. McEwen
United States Geological Survey
McLean, Virginia 22101

David H. Schaefer
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

Fred J. Thomson
Environmental Research Institute of Michigan
Ann Arbor, Michigan 48107

APPENDIX 2

A LIST OF PAPERS PRESENTED IN THE INTERPRETATION TECHNIQUES DEVELOPMENT SESSIONS AND SOME SELECTED PAPERS PRESENTED IN OTHER SESSIONS THAT CONTAINED PERTINENT RESULTS

AUTHOR(S)	TITLE
Algazi, Ralph V. (I10)	Digital Enhancement of Multispectral MSS Data for Maximum Image Visibility
Bernstein, Ralph (I7)	Results of Precision Processing (Scene Correction) of ERTS-1 Images Using Digital Image Processing Techniques
Billingsley, F. C. and A. F H. Goetz (I9)	Computer Techniques Used for Some Enhancements of ERTS Images
Cousin, S. B., J. F. Paris, J. F. Potter, and A. C. Anderson (I8)	Significant Techniques for the Processing and Interpretation of ERTS-1 Data
Evans, William E. and Sidney M. Serebreny (I15)	Analysis of ERTS Imagery Using Special Electronic Viewing/Measuring Equipment
Gramenopoulos, Nicholas (I17)	Terrain Type Recognition Using ERTS-1 MSS Images
Griggs, M. (I2)	Determination of Aerosol Content in the Atmosphere
Lachowski, H. M. and F. Y. Borden (I18)	Classification of ERTS-1 MSS Data by Canonical Analysis
Lamar, Jeannine and Paul M. Merifield (I12)	Pseudocolor Transformation of ERTS Imagery
Malila, William A. and Richard F. Nalepka (I1)	Atmospheric Effects in ERTS-1 Data, and Advanced Information Extraction Techniques

McEwen, Robert B. (I5)	Geometric Quality of ERTS-1 Images
Nichols, J. D. (I14)	Combining Human and Computer Interpretation Capabilities to Analyze ERTS Imagery
Rifman, Samuel S. (I6)	Digital Rectification of ERTS Multispectral Imagery
Rogers, Robert H. and Keith Peacock (I3)	A Technique for Correcting ERTS Data for Solar and Atmospheric Effects
Ross, D. S. (I4)	Masking Bulk RBV Images to Reduce Stationary Residual Errors in Radiometric Correction
Sabels, Bruno E. and Jerry D. Jennings (I13)	Digital Interactive Image Analysis by Array Processing
Shanmugam, K. and R. M. Haralick (I16)	Combined Spectral and Spatial Processing of ERTS Imagery Data
Tapper, Gerald O. and Robert W. Pease (I11)	ERTS-1 Image Enhancement by Optically Combining Density Slices
Yost, Edward and Sandra Wenderoth (I19)	In-Situ Spectroradiometric Quantification of ERTS Data

Supplemental Program

Conrod, Alfred C.	Digital Data Processing of ERTS-1 Imagery of Delaware Bay
Fraser, Robert S.	Effect of the Atmosphere on ERTS Observations

MULTIDISCIPLINARY/REGIONAL RESOURCE SURVEYS

Gilmore H. Trafford
NASA, Wallops Station
Wallops Island, Virginia

The Multidisciplinary/Regional Resource Surveys Session of the ERTS-1 Symposium was held on March 7, 1973. On March 9, 1973, an invited review panel conducted a detailed summary of these papers. The panel members are listed in Appendix 1, the papers in Appendix 2.

The Multidisciplinary/Regional Resource Surveys Summary is presented in four parts: Land Use, Geologic Interpretation, Resource Survey, and Pollution Monitoring.

LAND USE

Summary of Significant Results

Technology

The usefulness of ERTS MSS black-and-white and false-color imagery in the 0.5- to 0.8-micron region has been clearly demonstrated for land-use classification at regional, county, and city levels. County, regional, and foreign emphasis is now being placed on the need for more intensive research into improved change-detection methods, based on a deeper understanding of cultural ground-truth relationships affecting the image reflectances.

Applications

Pilot land-use mapping was made of natural and cultural features over a 500 square mile area in Columbus/Franklin County, Ohio, using a Spatial Data 32-color viewer in conjunction with ERTS. This mapping has established that natural and cultural features can be accurately mapped at scales in excess of 1:125, 000, at least for USGS recommended Level I land-use categories.

ERTS-1 imagery has been applied to the metropolitan areas of Riverside and San Bernardino in southern California (Bowden and Viellenave) and the metropolitan area of Washington, D. C. (Mallon) for updating urban land use. In addition, data have also been used to assess the recreational impact of vehicular racing activities on desert ecologies in southern California.

GEOLOGIC INTERPRETATION

Summary of Significant Results

Technology

The synoptic and good geometric value of ERTS MSS imagery for enhanced geologic interpretation has been established. Spatial filtering, as an image enhancement technique for lineament directional filtering, appears particularly promising for additional refinement at the user technology level.

Applications

The alignment and distribution of faults in much of south-central Oregon have been mapped at 1:1,000,000 on ERTS Band 5 (0.6 to 0.7 micron), and color reconstituted Bands 4, 5, and 6 (0.5 to 0.8 micron) (Simonson, Paine, Poulton, Laurence, Herzog, and Murray). Overlays of geologic features drawn from the imagery of the Gao region in the Republic of Mali (Mac Leod) have been compared with recent maps. The additional ERTS information has yielded more fault lines, more specific delineation of sand fields, and mapping of sedimentary pediments in the area. The western boundary of the Gao graben (a down-faulted block) is a potential petroleum or water source and has been precisely mapped from the available space imagery. There are many fascinating questions remaining concerning lineaments and desertification, particularly in relationship to drainage channels of the major rivers in Mali and the relationship of lineaments to former drainage channels. These answers can be sought now that a data base is becoming available to Mali via the ERTS imagery.

Although more than 1000 papers have been written about the geology of the western Alps, ERTS imagery has provided additional insight into this region (Fontanel, Guillemot, and Guy). Large features have shown up in ERTS imagery of the region between the Alps and the Pyrenees (southern France). These features have been tentatively interpreted as reflections of deep-seated wrench faults in the basement of the folded sedimentary series, which in the field are often hidden by small, complicated structures.

Preliminary study of the imagery taken by ERTS-1 of the southeast corner of Iran (Ebtehadj and Shazi) denotes the presence of a larger number of faults than has previously been recorded on geological maps. Two fairly large faults have been identified in the Isfahan area. This initial encouragement in the application of the ERTS-1 imagery has given rise to the assumption that a more detailed field-investigation program will be more fruitful than was otherwise assumed.

RESOURCE SURVEYS

Summary of Significant Results

Technology

The usefulness of ERTS MSS black-and-white and false-color imagery in the 0.5- to 1.1-micron region has been demonstrated at the county, regional, and foreign levels of interest. Additional emphasis is now being placed on the computer-aided extraction of local information. Foreign interests, also encouraged by their preliminary results, are now placing orders for additional image-processing equipment.

Applications

Agriculture and Forestry—Imagery in the MSS Band 5 (0.6 to 0.7 micron) has been found useful in North Carolina (Welby, Lammi, and Carson) for identifying forest clearings of five acres and less at a scale of 1:300,000. In Oregon (Simonson, Paine, Poulton, Laurence, Herzog, and Murray), additional emphasis has been placed on the development of algorithms to discriminate between new and old forest clearcuttings and to delineate Tussock moth damage. In order to enhance contrast between dry grasslands and shrub-steppe vegetation in Oregon, false color in the 0.5- to 1.1-micron range has also been used.

Color additive techniques have proved beneficial in the study of changes in available forage and high vegetation productivity during the rain-free periods in Mali, south Africa (Mac Leod). In Iran, further concentration is now being placed on establishing the tonal value of false color with respect to crops, trees, shrubs, and associated deforestation and timber-cutting activities.

Strip Mining—Provisions of the newly enacted strip-mining conservation laws in Ohio have generated a keen interest in studying the possibility of using ERTS data for surveying more than 61 million km^2 (250,000 acres). Although cloud cover has been a problem, experimental analysis of MSS Band 5 (0.6 to 0.7 micron) (Sweet, Wells, and Wukelic) has demonstrated that ERTS application, in this regard, is feasible with the exception of backfilling surveillance, due to insufficient resolution.

Water Resources—Simonson, Paine, Poulton, Laurence, Herzog, and Murray have shown that ERTS imagery has proven excellent for measuring the extent and increase in irrigation along the Oregon-Washington border near the Columbia River. In Africa (Mali Republic), imagery digital analysis has been applied to the Office du Niger irrigation scheme (Mac Leod), resulting in new insight into the hydrology of the region. Water resource investigations in Iran (Ebtehadj and Shazi) also show that ERTS imagery is significant; in the field of hydrology wherein the location of lakes, location, areal extent, seasonal fluctuation, and quality of water may be assessed along with river drainage patterns and marine phenomena in the Persian Gulf.

POLLUTION MONITORING

Summary of Significant Results

Technology

MSS Band 5 (0.6 to 0.7 micron) coupled with the synoptic view afforded by ERTS has provided clearly contrasted overviews of sediment stream loading, lake sedimentation, and offshore efflux, and also proved effective in monitoring smoke plumes on a repetitive basis.

Applications

Sediment pollution in North Carolina (Welby, Lammi, and Carson) has been identified and correlated with in-situ loading estimates. Possible sources of sediments have been identified to the extent where the feasibility of studying the interrelationship of this form of pollution with urbanization and intensified land use is considered a major benefit from ERTS Band 5.

A study of pollution at sea in the western Mediterranean (Fontanel, Guillemot, and Guy) has demonstrated that industrial waste containing ferrous oxides and sulfuric acid can be clearly delineated at a scale of 1:1,000,000; however, cloud cover can prove to be a severely limiting problem for routine operational surveillance by satellite. The small-scale ERTS imagery has been found to be particularly useful for observing a very large scale anomaly extending some 180 km along the Spanish shoreline and about 180 km off the coast.

A study of the ERTS-1 imagery of the southeast corner of the Caspian Sea and the northwest region of the Persian Gulf (Ebtehadj and Shazi) has shown that the discharge of stream sediments into the Persian Gulf and the Caspian Sea and the nature of the offshore currents may be determined. In Ohio, smoke plumes have been identified in ERTS MSS Band 5 (0.6 to 0.7 micron) imagery that has been magnified 140 times. The demonstrated ability of ERTS to detect major smoke plumes on a repetitive basis will be used in conjunction with meteorological data to evaluate and verify the states' air movement models (Sweet, Wells, and Wukelic).

CONCLUSIONS

The synoptic value of ERTS small-scale resolution has been clearly demonstrated by the cross section of papers presented in the session, with the exception of urban land-use planning requiring higher resolution. Because of the complex interrelationships existing with broad overview photography offered by ERTS, it should not be viewed as a single source of data, but rather as a supplementary source in conjunction with more specific data sources such as supporting aircraft overflights and in-situ monitoring at key points of interest. For this reason, regional efforts should be integrated and refined as key future experimental packages, within which the individual investigations characterizing the ERTS-1 approach would give way to a regional multidisciplinary team approach for ERTS-B.

Now that the initial uses of ERTS have been clarified and confirmed, the difficulties of blockage due to cloud cover must be attacked if future operational cost effectiveness is to be measured in terms of a continuous supply of seasonal-dependent event sequences. A sincere attempt must also be made to extract relevant information beyond the image annotation level, and to train users at the local level in its use through regionally coordinated efforts.

It was generally agreed by the review panel that all bands of the MSS are effective and that color enhancement is particularly useful. Spatial filtering techniques should be encouraged as a relatively cheap form of parallel processing for reducing computerized preprocessing costs.

Although the use of the Data Collection System (DCS) was not brought out as a major session topic, it was felt that there will be a growing demand for DCS support, especially in view of the focusing ability of ERTS remote sensing to identify areas in which there are more concentrated ground-based investigations requiring shorter time constants for control measures.

APPENDIX 1

PARTICIPANTS IN ERTS-1 MULTIDISCIPLINARY/REGIONAL RESOURCES SURVEY WORKING GROUP

Art Alexiou
National Sea Grant Program NOAA
Rockville, Maryland 20852

John C. Antennucci
Maryland Department of State Planning
Baltimore, Maryland 21201

Louis H. Bauer
Goodyear Aerospace Division
Litchfield Park, Arizona 85340

Leonard Bowden
University of California
Berkeley, California 94720

Alfred Conrod
Bendix Aerospace Division
Ann Arbor, Michigan 48107

Ben Drake
Environmental Research
Institute of Michigan
Ann Arbor, Michigan 48104

Andri Fontanel
Institut Francais Du Petrole France
Malmaison, France

David Keller
G. E. Space Division
Philadelphia, Pennsylvania 19101

Charles Leigh
IREQ Research Institute
Quebec, Candaa

Harry J. Mallon
Metropolitan Washington Council
of Governments
Washington, D. C. 20036

David Oberholtzer
NASA, Wallops Station
Wallops Island, Virginia 23337

Robert Stewart
NASA, Johnson Space Center
Houston, Texas 77058

Gilmore H. Trafford, Chairman
NASA, Wallops Station
Wallops Island, Virginia 23337

Donald E. Walsh
Old Dominion University
Norfolk, Virginia 23508

Edward A. Ward
MITRE Corp.
McLean, Virginia 22101

Charles W. Welby
North Carolina State University
Raleigh, North Carolina 27607

APPENDIX 2

PAPERS PRESENTED IN THE MULTIDISCIPLINARY/ REGIONAL RESOURCES SURVEY SESSION

AUTHORS(S)	TITLE
Bowden, Leonard W., and James Viellenave (R4)	Assessment of Southern California Environment from ERTS-1
Ebtehadj, Khosro, and A. Shazi (R8)	Application of ERTS-1 Imagery in the Fields of Geology, Agriculture, Forestry, and Hydrology to Selected Test Sites in Iran
Fontanel, A., J. Guillemot, and M. Guy (R6)	First ERTS-1 Results in Southeastern France: Geology, Sedimentology, Pollution at Sea
Mac Leod, N. H. (R5)	Applications of Remote Sensing (ERTS) to Resource Management in Sahelien Africa (Republic of Mali)
Mallon, Harry J. (R7)	Use of ERTS-1 Data for Regional Planning in the Metropolitan Washington Council of Governments–A Short Brief
Simonson, G. H., D. P. Paine, C. E. Poulton, R. D. Laurence, J. H. Herzog, and R. J. Murray (R2)	Natural Resource Inventory and Monitoring in Oregon with ERTS
Sweet, David C., Terry L. Wells, and George E. Wukelic (R3)	Resource Management Implications of ERTS-1 Data to Ohio
Welby, Charles W., Joe O. Lammi, and Robert J. Carson (R1)	Multidisciplinary Application of ERTS-1 Data to North Carolina Natural Resource Management

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